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OF THE

AMERICAN PHYSICAL SOCIETY

INCLUDING THE

PROGRAMME OF THE

1961 ANNUAL MEETING

AT

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February 1–4, 1961

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February 1, 1961 Series II, Vol. 6, No. 1, Part 1

BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

1961 Annual Meeting at New York, February 1–4, 1961

THE **1961 Annual Meeting of The American Physical Society will be held at New York** on Wednesday, Thursday, Friday, and Saturday, **February 1–4, 1961.** The American Association of Physics Teachers (hereinafter to be denoted by AAPT) will share in the Ceremonial Session and in the banquet. The headquarters hotel is once more the New Yorker.

In 1960 we were troubled by the memory of overcrowded sessions in small halls, and so we bought size of halls at the expense of propinquity and of money. This year we have gone further in the same direction. Now we have a large hall in the Martinique Hotel at 32nd Street and Broadway, in addition to big ones in the New Yorker and in the Statler-Hilton. The hall in the Martinique is assigned to the theoretical physicists from Wednesday through Friday; we hope that they will not feel lonesome; whether or not they do, they will have the opposite experience on Saturday, when they will be divided between two smaller rooms in the New Yorker. We intend also to enlarge the availability of the "vu-graph," hoping that speakers will more and more prefer it to the blackboard in all except the Panel Room and the Boston-Washington Room. By the time this Bulletin appears, all of the speakers should have received a memorandum from our Committee on the Character of Meetings, adjuring them to be intelligible and giving them useful hints on how to prepare, how to speak, and how to use the vu-graphs. (We do not send this to more than one of the people named in the by-line of a joint paper; if you are the one who receives it, but not the one who is to give the joint paper, please send it to the latter.)

The **headquarters hotel is the New Yorker,** which is at Eighth Avenue and 34th Street, a block north of the northwest corner of Penn Station (with which it is connected by underground passage). Those who have not yet made their room reservations should do so at once, preferably availing themselves of the form which is printed on page 87 of this Bulletin. Penn Station together with the underground passage aforesaid offers a covered way from the New Yorker to the Statler-Hilton (east of the station), and there is an additional covered way under the south sidewalk of 33rd Street by which you can go all of the way to the Martinique.

The **registration desk** will be located in the North Ballroom Foyer on the mezzanine floor of the New Yorker—same place as in each of the last four years. Banquet tickets will be sold there up to 6:00 p.m. on Thursday. There will be bulletin boards for messages and blackboards for notice of change of arrangements should any be needful. Post-deadline papers may be announced on sheets of paper to be distributed at the registration desk. Exceptionally, on Tuesday evening, January 31, between 5:00 p.m. and 10:00 p.m., those who come early may register in the lobby of the New Yorker; and they will be extremely wise to do so, so that they may prepare themselves for the stresses of the meeting by lying late abed the next morning while the others mill around the desks.

The **registration fee** stays once more at the modest figure of $2.00. We insist on registration, and we do not accept messages to be posted from or for anyone who has not registered.

The **banquet** of The American Physical Society and the AAPT will be held on Friday evening at 7:00 p.m. in the Grand Ballroom of the New Yorker. The after-dinner speaker will be H. A. Bethe of Cornell University, and his title is "Scientists and Politics." You must buy your tickets either in advance or at the registration desk not later than 6:00 p.m. on Thursday: the hotel will set places for only 5% over and above the number paid for at that time. If you want to avoid queuing up by buying in advance, the way to do it is to send your check (made out to American Physical Society) to Mrs. Emily Wolf, American Institute of Physics, 335 East 45 Street, New York 17, New York: the

tickets will be held in your name at the desk until it closes on the day of the dinner. The price will be $5.00.

Cocktails will be sold in the Panel Room and the North Ballroom from 6:00 p.m. on Friday evening, but the consumers must pay for these themselves.

The **Joint Ceremonial Session** of the two Societies will be held according to ritual in Manhattan Center (just west of the New Yorker) on Thursday at 2:00 p.m. Our Retiring President, V. F. Weisskopf, will deliver his address which will be entitled "Problems of Nuclear Structure." The Chairman for this part of the session will be our incoming President, Frederick Seitz. After the delivery of our Retiring Presidential Address, the chair is taken over by Leonard Olsen, Retiring President of the AAPT, and the programme becomes that of the AAPT. The Oersted Medal will be presented to J. R. Zacharias, and the twentieth Richtmyer Memorial Lecture will be given by W. A. Fowler under the title "Some Implications of Nucleosynthesis in Stars."

The **Oliver E. Buckley Solid-State Physics Prize** of 1961 will be awarded at the banquet to Walter Kohn.

Invited papers on the general programme comprise two groups, one forming a Symposium on General Relativity (speakers: J. A. Wheeler, P. G. Bergmann, R. P. Feynman, and Thomas Gold) and the other what is in effect a Symposium on Fission (speakers: J. J. Griffin, James Terrell, J. C. D. Milton, and E. Melkonian). The former of these was arranged by P. G. Bergmann and the latter by the Deputy Secretary. Other invited speakers on the general programme are P. Aigrain, Michel Baranger, S. D. Bloom, N. E. Booth, D. A. Bromley, Bernard Cohen, C. E. Engelke, H. P. Furth, R. L. Garwin, E. L. Hahn, W. N. Hess, M. H. Hull, Jr., P. D. Johnson, W. A. S. Lamb, Benjamin Lax, Lloyd Mann, R. L. Mössbauer, R. W. Morse, J. J. Murray, James Raz, Frederick Reif, Juan Roederer (the first speaker from Argentina ever to address this Society), Horace Taft, S. Teitler, A. M. Thorndike, and R. R. Wilson.

Our **Division of Electron Physics** has set up a session of three invited papers to be given by A. V. Phelps, Peter Franken, and S. J. Buchsbaum.

Our **Division of Solid-State Physics,** in partial collaboration with Bell Telephone Laboratories, has set up two half-day sessions of invited papers. One of these consists of four papers by L. Esaki, L. Giaever, D. G. Thomas, and R. G. Shulman. The title of the other is "Optical Masers and Related Subjects," and it consists of three speeches by H. Weakliem, A. L. Schawlow, and T. H. Maiman: with it is joined a sequence of six contributed papers on masers. We have the Grand Ballroom of the Statler-Hilton for one half-day, and one only, and we have chosen this session to occupy it on Saturday morning. It is rare to schedule invited papers for the *latter part* of a Saturday-afternoon session, but we cannot give two half-day sessions to one Division at one of our huge meetings without requiring that one be assigned to Saturday afternoon.

Four hundred and twenty-six contributed papers are distributed among thirty-seven sessions. This again is a record number for a New York meeting, exceeding by seven the total of 1960. It still falls short by twenty-seven of the number constituting the all-time, all-place record, set at Washington in 1959.

The sensation of this meeting is the population-explosion of ten-minute papers in theoretical physics. There were eighty of these year before last, ninety last year, and this year one hundred and fifteen! For the first time in our history it was necessary to schedule simultaneous sessions of contributed papers in theoretical physics. Only five out of nine sessions are exempt from competition with each other, the other four are paired. Also there must be competition between theories and the experiments that they profess to explain, not to speak of competition between other sessions. We are braced for an unusual afflux of acrimonious remarks from physicists who through want of experience believe it possible to arrange forty-nine sessions in seven groups of seven each in such a way that no one can possibly want to hear more than one of the sessions in each of the groups. The distribution of the papers in theoretical physics was done by Robert Serber, to whom (not for the first time) the theorists and the Secretary owe a great debt. The distribution of papers among sessions I, MA, Q, QA, TA, U, X, and XA was done by the Deputy Secretary.

The **AAPT announces a Symposium** "Topics in the History of Modern Physics" so enticing that we much regret our inability to save it from competition by sessions of our own. It is scheduled for Friday afternoon, and it gets the Grand Ballroom of the Hotel New Yorker, the largest room at our disposal at that time. The anticipated speakers are C. D. Anderson, A. H. Compton, I. I. Rabi, W. F. G. Swann, and Sir George Thomson, each to talk on the history of a field in which he is a conspicuous figure. The eventual titles will be published in the programme of AAPT, to be distributed at the registration desk.

The **Business Meeting of The American Physical Society** will be held at 4:45 p.m. on Wednesday in the Terrace Room of the New Yorker—same hour, but not same place, as last year.

The **Business Meetings of the Divisions** of Electron Physics and Fluid Dynamics are announced in the Epitome and the Main Text.

The **Council of The American Physical Society will convene** on Tuesday, **January 31,** at 10:30 a.m. in the building of the American Institute of Physics at 335 East 45 Street, unless contrary notice is sent to its members.

The American Institute of Physics will conduct a **Placement Register** on the fifth floor of the Hotel New Yorker, February 1–4. It will be open from 9:00 a.m. to 9:00 p.m. on Wednesday and Thursday, from 9:00 a.m. to 6: p.m. on Friday; and from 9:00 a.m. to noon on Saturday.

Post-deadline ten-minute papers pertaining to very recent achievements of very special importance will be considered for admission to the "special supplementary programme" if the abstracts are received at the office of the Society not later than Friday, January 28. The titles of such as are accepted will be distributed on mimeographed sheets at the registration desk, and the papers may be given under the usual ten-minute rule in Session GA, or perhaps some of them at the ends of sessions relevant to their topics if the relevant sessions are short enough to permit of extension.

Preliminary announcements of the Monterey and Washington meetings appear on page 89 of this Bulletin. We do not always print the first announcement of the Washington meeting so early, but this year you will see a special reason when you read it. On page 94 is published the Calendar of Meetings and Deadlines up to the end of this year, and on page 95 the rules for the preparation of abstracts which we commend to the attention of every member. Please take note of the newer instructions printed in italics after the older ones, and also of the admonitions as to times of mailing of abstracts which are printed under the calendar. We add a new admonition. It is becoming increasingly obvious that what we believe are called "manila" envelopes, big enough to contain an abstract unfolded, do not travel through the mails so fast as envelopes of the size that the postoffice calls Number 8, roughly $9\frac{1}{2}$ by $4\frac{1}{4}$ inches. In fact it looks as though these tend to travel as third-class mail even though they carry first-class postage. Better avoid them.

Errata pertaining to the contents of this issue will be published in a later issue of the Bulletin if received not later than Monday, February 4, by Miss Ruth Bryans, American Institute of Physics, 335 East 45 Street, New York 17, New York. Do not send in a copy of your abstract marked with corrections. Write out your corrections in the form "Instead of . . . read. . . ." or, if you prefer, "replace the sentence beginning with the words . . . by the following sentence. . . ." Add nothing.

KARL K. DARROW, *Secretary*
American Physical Society
Columbia University
New York 27, New York

EPITOME OF THE 1961 ANNUAL MEETING

(Personal names are those of invited speakers.)

In case of discrepancy between a time indicated here and the corresponding time indicated in the Main Text, it is the latter that prevails.

Wednesday Morning

10:15	A.	Astrophysics; fission; Mössbauer effect. New Yorker, Grand Ballroom.
10:45	B.	Accelerators; Cranberg. S-H, Terrace Ballroom West.
10:45	BA.	Cohen, Raz. New Yorker, Terrace Room.
10:30	C.	Electronic properties of solids. S-H, Terrace Ballroom East.
11:00	D.	Ferroelectricity. S-H, Terrace Lounge.
10:15	DA.	Theoretical physics I: atomic physics. Martinique.

Wednesday Afternoon

1:45	E.	Theoretical physics II: statistical mechanics and many-body problems. Martinique
2:00	EA.	Nuclear fission: Griffin, Terrell, Milton, Melkonian. New Yorker, Grand Ballroom
2:00	F.	Thorndike, Taft, Booth, Murray. New Yorker, Terrace Room.
2:00	FA.	Semiconductors I (compounds), Teitler. S-H, Terrace Ballroom East.
2:00	G.	Mostly magnetic resonance. New Yorker, Panel.
2:00	GA.	Plasma physics; post-deadline papers, if any. S-H, Terrace Ballroom West.
2:00	H.	Crystals. New Yorker, Boston-Washington.

Wednesday Afternoon

4:45		Business Meeting of The American Physical Society. New Yorker, Terrace Room.

Thursday Morning

10:00	I.	Nuclear reactions I. S-H, Terrace Lounge.
9:30	IA.	Semiconductors II (elements, theory). S-H, Terrace Ballroom West.
9:45	J.	Electron physics; irradiation effects; lattices. S-H, Terrace Ballroom East.
9:45	JA.	General physics. New Yorker, Panel.
9:45	K.	Symposium on general relativity: Wheeler, Bergmann, Feynman, Gold. New Yorker Terrace Room
9:45	KA.	Theoretical physics III: hyperfragments; weak interactions; many-body systems. Martinique.
9:45	L.	Mössbauer, Wilson, Furth. New Yorker, Grand Ballroom.

Thursday Afternoon

2:00	LA.	Joint Ceremonial Session of APS and AAPT: Weisskopf, Sears, Zacharias, Fowler. Manhattan Center.

Friday Morning

9:45	M.	Division of Electron Physics: Phelps, Franken, Buchsbaum. Business Meeting of the Division of Electron Physics. New Yorker, Grand Ballroom.
9:30	MA.	Nuclear reactions II. S-H, Terrace Ballroom West.
9:45	N.	Mesons, strange particles, antiprotons. S-H, Skytop.
10:00	NA.	Fluid dynamics; Business Meeting of the Division of Fluid Dynamics. New Yorker, Panel Room.
9:45	O.	Bloom, Mann, Baranger, Bromley. New Yorker, Terrace Room.
9:30	OA.	Theoretical physics IV: classical and quantum theory. Martinique.
10:15	P.	Apparatus of nuclear physics. S-H, Terrace Ballroom East.

Friday Afternoon

2:00 Q. Nuclear reactions III. S-H, Terrace Ballroom West.

2:00 QA. Beta and gamma spectroscopy I. New Yorker, New Orleans Room.

2:00 R. Cosmic rays. New Yorker, Terrace Room.

2:00 RA. Magnetism. S-H, Terrace Ballroom East.

2:00 S. Theoretical physics V: scattering theory. Martinique.

2:00 SA. B. Lax, Aigrain, Morse, Johnson. S-H, Skytop.

Friday Evening at 7:00

Banquet of The American Physical Society and AAPT; Bethe. New Yorker, Grand Ballroom.

Saturday Morning

9:30 T. Theoretical physics VI: field-theory I. New Yorker, Boston-Washington Room.

9:30 TA. Neutrons I. S-H, Penn Top South.

9:30 U. Nucleonic scattering; fundamental particles; Hull, Engelke. New Yorker, Grand Ballroom.

9:30 UA. Reif; cryogenics. S-H, Skytop.

9:30 V. Roederer, Hess, Lamb, Garwin. New Yorker, Terrace Room.

9:30 VA. Theoretical physics VII: nuclear reactions. New Yorker, Panel Room.

9:15 W. Division of Solid-State Physics: Weakliem, Schawlow, Maiman; masers. S-H, Grand Ballroom.

Saturday Afternoon

1:30 WA. Esaki, Giaever, Thomas, Shulman. New Yorker, Grand Ballroom.

1:30 X. Neutrons II. S-H, Penn Top South.

1:30 XA. Beta and gamma spectroscopy II. New Yorker, New Orleans Room.

1:30 Y. Hahn; hyperfine structure; nuclear spins. New Yorker, Terrace Room.

1:30 YA. Mechanical and thermal properties of solids. S-H, Skytop.

1:30 Z. Theoretical physics VIII: nuclear structure. New Yorker, Panel Room.

1:30 ZA. Theoretical physics IX: field-theory II, dispersion relations. New Yorker, Boston-Washington Room.

PROGRAMME

WEDNESDAY MORNING AT 10:15

New Yorker, Grand Ballroom

(JAMES TERRELL presiding)

Astrophysics; Fission; Mössbauer Effect

A1. Production of Light Elements in Stellar Atmospheres.* I. Deuterium and He^3. STANLEY BASHKIN† AND DAVID C. PEASLEE, *Australian National University.*—The origin of the observed abundances of deuterium and He^3 is attributed to nuclear reactions by energetic protons in stellar atmospheres. The fast protons are assumed to occur in flares such as generate cosmic-ray protons on the sun, which is used as a model. For deuterium, the reactions considered are $p+p \rightarrow d+\pi^+$; $p+(\mathrm{He,C,N,O,Ne}) \rightarrow d+(x)$; $p+(\mathrm{He,C,N,O,Ne}) \rightarrow n+(y)$ followed by $n+p \rightarrow d+\gamma$. For He^3 the important reactions are $p+(\mathrm{He,C,N,O,Ne}) \rightarrow \mathrm{He}^3+(z)$. The calculations are based on Parker's energy spectrum of flare-accelerated protons, estimates of solar flare size and frequency, experimental or estimated reaction cross sections, astronomical data on the constitution of the solar atmosphere and the evaporation of matter from the sun, and estimates of the consumption of deuterium by mixing to the stellar interior. The results are that the He^3 and deuterium abundances are smaller by 10^3 and 2×10^4 times, respectively, than the "universal" values; but since the flare activity of the sun appears exceptionally quiet in comparison with other stars, the proposed mechanisms may account for the "universal" abundances.

* Supported in part by the U. S. Atomic Energy Commission.
† Fulbright Research Scholar on leave from, but now returned to, the State University of Iowa.

A2. Production of Light Elements in Stellar Atmospheres.* II. Lithium, Beryllium, and Boron. DAVID C. PEASLEE AND STANLEY BASHKIN,† *Australian National University.*—Computations similar to those of the preceding abstract[1] have been carried out for the spallation reactions $p+(\mathrm{C,N,O,Ne}) \rightarrow (\mathrm{Li,Be,B})+(x)$. In addition to the production of the light isotopes, some account is taken of loss resulting from convective mixing into the hot interior of the sun. It is found that the sun can be expected to expel approximately one to three orders of magnitude too little of these isotopes to be fully responsible for the "universal" abundances; but, as in I, other stars appear likely to make up the necessary amounts. Observed Li^6/Li^7 and B^{10}/B^{11} ratios appear to be a direct result of the spallation process alone. The reduction of relative Li/Be abundance observed in the sun suggests on the present model that the period of mixing of surface material with the interior is rather short, of the order of 10^5 yr. Much of the reaction data needed to improve the calculations of these abundances is still unavailable, and attention is called to particular cross sections, knowledge of which would be of great interest.

* Supported in part by the U. S. Atomic Energy Commission.
† Fulbright Research Scholar on leave from, but now returned to, the State University of Iowa.
[1] Stanley Bashkin and David C. Peaslee (preceding abstract).

A3. Neutrino Production Processes in Stars.* ROBERT C. STABLER, *Ford Motor Company,* AND HONG-YEE CHIU, *Institute for Advanced Study.*—In addition to the urca process of Gamow and Schoenberg,[1] at least two other processes may provide large energy losses in the form of neutrinos from stars at high temperatures. These are the Pontecorvo process,[2] $e^-+A^+ \rightarrow e^-+A^++\nu+\bar{\nu}$, and the photoneutrino process, $\gamma+e^- \rightarrow e^-+\nu+\bar{\nu}$. The existence of both of these reactions is implied by the Feynman and Gell-Mann theory of weak interactions. In contrast to the urca process (electron capture followed by beta decay with the attendant emission of a neutrino-antineutrino pair) these processes have no threshold. However, they exhibit a strong energy dependence arising from the increase in phase space and the "strength" of the weak interaction with energy. The relevant cross sections and energy losses have been calculated for both of these reactions for both relativistic and nonrelativistic energies and for degenerate and nondegenerate electrons. An interesting feature of the photoneutrino matrix elements is that all of the integrals may be performed analytically. Typical values for the energy loss from this process are 10^4 ergs/g-sec at 10^9 °K and 10^{11} ergs/g-sec at 10^{10} °K. The significance of these results with regard to stellar evolution will be discussed.

* Part of this work was performed at Cornell University and was supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] G. Gamow and M. Schoenberg, Phys. Rev. 59, 539 (1941).
[2] B. Pontecorvo, Soviet Phys.—JETP 36, 1615 (1959); G. Gandel'man and V. Pinaev, *ibid.* 37, 1072 (1959).

A4. Miniature U-238 Fission Counter. GEORGE DANIEL HICKMAN, *Knolls Atomic Power Laboratory.*—*A small, ¼-in. diameter by ½ in. in length, fast neutron fission counter probe employing highly depleted uranium as the fission material has been developed.[1] The isotopic analysis[2] of the uranium, obtained by the 3-stage mass spectrometer at this Laboratory, is as follows: U-238 (essentially 100%); U-236 (0.03±0.02 ppm); U-235 (0.90±0.20 ppm); and U-235 (0.04±0.02 ppm). The uranium deposit was 1.72 mg/cm². Detailed measurements of the fast neutron flux in the Flexible Plastic Reactor (10^{5}–10^{6} $\mathrm{ncm^{-2}\,sec^{-1}}$) at KAPL, obtained with the U-238 fission counter, have shown it to be insensitive to both thermal neutrons, even without a thermal (Cd) shield, and to high energy (>5.3 Mev) gamma rays. The gamma sensitivity, photofission of the U_3O_8, was checked in the critical assembly by making a fast neutron flux scan with red phosphorus (½-in.×$\frac{1}{16}$-in.) pellets. Since the (n,p) threshold reaction in phosphorus (~1 Mev) is approximately the same as the (n,f) reaction in U-238, the two scans should yield, as is found to be the case, identical results provided there is no appreciable influence of photofission in the U_3O_8.

* Operated by the General Electric Company for the U. S. Atomic Energy Commission.
[1] Counter fabrication by Westinghouse Electronic Tube Department, Elmira, New York.
[2] Performed by the Mass Spectrometer group at the Knolls Atomic Power Laboratory.

A5. Mass-Angle Correlation in Neutron Fission of U^{238}.* J. H. MANLEY, *Los Alamos Scientific Laboratory.*—Measurement of 3200 fission fragment pairs from neutron-induced fission in U^{238} as recorded in emulsions with marked fission origin has been completed and analyzed. The neutron energy range was from 1.4 to 1.7 Mev, covering a region of known angular anisotropy. No significant variation in angular distribution between three different range-ratio categories—1.0–1.15, 1.15–1.50, >1.50—was observed beyond the statistical variations of about 15%.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

A6. Mass Distribution of Fission Fragments in the Thermal Neutron Fission of U^{235}.* G. J. SAFFORD, I. SCHRÖDER, J. A. MOORE, AND E. MELKONIAN, *Brookhaven National Laboratory and Columbia University.*—This mass distribution is being investigated with two solid state detectors facing each other at a distance of 1 cm and a deposit of U^{235} on a VYNS foil midway between them. (U^{235} deposited on the surface of a detector was found to diffuse slowly into the detector.) The quality of the detectors is indicated by the 15/1 ratio of counts in the light fragment peak to that in the valley. The mass distribution is derived from the energies of the fission fragments by the relation $M_1/(M_1+M_2)=E_2/(E_1+E_2)$. In one set of measurements, an electronic dividing circuit computed the ratio $E_2/(E_1+E_2)$, yielding the mass distribution for the fragments in the total kinetic energy range $\Delta(E_1+E_2)$ of about 20 Mev centered at the peak of the distribution. The familiar double peaked curve with a peak-to-valley ratio of better than 500/1 was obtained. In another, the mass distributions were determined for a series of 4-Mev intervals of the total kinetic energy by observing the kinetic energy distribution of one fragment in coincidence with (E_1+E_2) in the corresponding intervals. The peak-to-valley ratio increases rapidly with increasing total kinetic energy.

* This work partially supported by the U. S. Atomic Energy Commission.

A7. Neutron Induced Fission Cross Sections of Pu^{241} and Am^{243}.* DANIEL K. BUTLER, *Argonne National Laboratory.*—The neutron-induced fission cross sections of Pu^{41} and Am^{243} have been measured from 0.030 to 1.8 Mev and from 0.3 to 1.6 Mev, respectively. Both measurements were made relative to the fission cross section of U^{235} using a back-to-back gas scintillation counter. The masses of the plutonium and americium samples were determined by alpha counting. The mass of the U^{235} sample was determined by quantitative electrodeposition. Neutrons were produced with a $Li^7(p,n)Be^7$ target using protons from a 3-Mev electrostatic generator. The Pu^{241} cross section was found to have an energy dependence similar to that of U^{235} above 200 kev and a value of 1.8 b at 1.0 Mev. The Am^{243} cross section was found to rise from a value of 0.01 b at 0.3 Mev to a plateau of 1.2 b above 1.3 Mev.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

A8. Subthreshold Fission—U^{234}, U^{236}, U^{238}, Pu^{242}, and Pa^{231}. B. R. LEONARD, JR., AND R. H. ODEGAARDEN, *General Electric Company, Richland.*—Measurements have been made of the fission component of low neutron energy resonances of five additional nuclei which exhibit fast neutron fission threshold behavior. These measurements were carried out by use of a crystal spectrometer and samples of enriched isotopes. The best estimates or upper limits obtained for the peak resonance fission cross sections are as follows:

Nucleus	E_o(ev)	σ_{of}(barns)
U^{234}	5.20	50 ± 9
U^{236}	5.49	<1
U^{238}	6.68	<0.15
	10.2	<0.26
Pu^{242}	2.65	<41
Pa^{231}	0.396	0.255 ± 0.100
	0.496	0.185 ± 0.140
	0.745	0.075 ± 0.040

These results imply characteristic energies associated with the fast fission barriers similar in value to those previously obtained for Pu^{240} and Np^{237}. The resonance fission cross sections also are used to obtain improved estimates of the thermal neutron fission cross-section values.

A9. Mössbauer Effect of Fe^{57} in Al_2O_3. G. K. WERTHEIM, *Bell Telephone Laboratories.*—The Mössbauer effect of stable Fe^{57} and of the Fe^{57m} decay product of Co^{57} has been observed in Al_2O_3 over a wide range of temperature. In one set of experiments a source prepared by diffusing Co^{57} into Al_2O_3 at 1000°C was used in conjunction with an unsplit absorber. At the highest temperatures, the emission spectrum consists largely of two closely spaced lines characteristic of quadrupole splitting. The spacing corresponds to a value of $0.32\pm0.06\times10^{-24}$ cm² for the quadrupole moment of the 14.4-kev level of Fe^{57}. There is also a subsidiary emission line which at 298°K appears 5.8×10^{-6} ev above the centroid of the dominant pair of lines. The energy of this line, which may correspond to iron displaced from normal lattice sites, is strongly temperature dependent. At lower temperatures (77°K to 4°K) the spectrum smears out and finally disappears. It has been suggested by M. Goldhaber that such effects can arise after electron capture in dielectrics from the production by Auger effect of multiply ionized atoms which will have a range of nuclear isotope shifts. This offers an alternate explanation for the subsidiary line discussed above. The fact that the lifetimes of these atomic states may be comparable to the 10^{-7} sec half-life of the 14.4-kev level may contribute to the broadening.

A10. Mössbauer Effect of Ni^{61} in Applied Magnetic Fields. F. E. OBENSHAIN AND H. H. F. WEGENER, *Oak Ridge National Laboratory.*—We observed the Mössbauer effect for Ni^{61} with a metallic nickel source and absorber in applied magnetic fields to determine the magnetic moment μ_e of the first excited state. The magnetic hyperfine structure splitting $\mu\cdot H$ in Ni^{61} is of the same order of magnitude as the natural line width Γ. The Mössbauer spectrum $M(v)$, therefore, will not show well-separated lines as in the Fe^{57} case, but it will deviate from the Lorentz shape. The particular shape of $M(v)$ depends on the spins of the involved states, the gamma-multipole character, the magnetic field directions in source and absorber relative to the gamma-direction, and on $(\mu\cdot H)/\Gamma$ in source and absorber for both nuclear states. We have calculated $M(v)$ for $E1$, $M1$, $E2$, and $M2$ radiation as a function of the parameters involved. A comparison of theory and experiment will be presented.

WEDNESDAY MORNING AT 10:45

Statler-Hilton, Terrace Ballroom West

(R. L. COOL presiding)

Accelerators

B1. Accelerated Orbits in the Central Region as a Three-Sector Cyclotron.* M. M. GORDON AND H. G. BLOSSER, *Michigan State University.*—Digital computer studies have been carried out on the properties of accelerated orbits in the central region of a three-sector cyclotron in order to determine: (a) how well the beam will survive the $\mu_r=3/3$ resonance instability; (b) how much distortion of the beam's phase space area will result from this resonance; (c) how much axial focusing can be achieved effectively in an isochronous field. The field data are obtained from a model magnet facility which is a one-sixth scale replica of the proposed M.S.U. cyclotron magnet. The results are quite dependent on the acceleration rate;

these studies used both 280 kev/turn and 140 kev/turn. With 280 kev/turn a relatively large phase space area is transmitted through the resonance with only a modicum of distortion; with 140 kev/turn the transmitted area is quite curtailed and the distortion is markedly greater. In both cases the axial focusing achieved is relatively good; the results indicate an initial effective $\mu_z \cong 0.05$, compared with an eventual $\mu_z \cong 0.2$, and a corresponding amount of axial damping results.

* Work supported in part by the U. S. Atomic Energy Commission.

B2. Performance Estimate for a 40-Mev Cyclotron.* H. G. BLOSSER AND M. M. GORDON, *Michigan State University.*—Digital computer studies of a proposed 3-sector, variable energy cyclotron have advanced sufficiently to allow detailed performance estimates. An accelerating voltage of 280 kev/turn and usable axial aperture of 25 mm are assumed. A non-isochronus field designed to maximize axial focusing is employed near the center. At intermediate radii the field reverts to isochronus form with radial tune passing through 3/3 in the transition; effects of this transition have been investigated in detail.[1] Extraction is accomplished by a resonance system in which the radial tune passes again through 3/3 but with an added field component of amplitude 1% and $\cos\theta$ azimuthal dependence which opens a stop band; performance of such an extraction system also has been studied in detail. By estimating source performance from results of Smith[2] and taking account of space charge effects to first approximation, a 40-Mev external proton beam of 2.8 ma is inferred with energy spread of ± 30 kev and with radial and axial full-width full angle spreads of 4 and 20 milliradian cm, respectively.

* Work supported in part by U. S. Atomic Energy Commission.
[1] J. E. Stover, Michigan State University Cyclotron Project Rept. #3 (1960).
[2] W. I. B. Smith, "Sector focused cyclotrons," Natl. Acad. Sci.-Natl. Research Council 656, 183 (1959).

B3. Vibrating Target for the Improvement of Synchro-cyclotron Duty Cycle.* JEROME ROSEN, *Columbia University.*—The design and operation of a vibrating target for synchro-cyclotron use will be described. The target provides a tenfold decrease in cyclotron duty cycle while resulting in no appreciable decrease in external meson beam intensity relative to a conventional fixed target. This type of beam ejection requires, first, the formation of a coasting proton beam. This is accomplished by turning off the rf Dee voltage at a time corresponding to a suitable radius. The target is then brought up into the beam, intercepting protons with progressively smaller vertical oscillations. The ejection time is then essentially determined by the motion of the target.

* This research is supported by the Office of Naval Research and the U. S. Atomic Energy Commission.

B4. Effect of Field Perturbation in a Two-Way Accelerator.* G. PARZEN, *Midwestern Universities Research Association.*—The effect of various perturbations on the magnetic field in the MURA two-way electron accelerator has been studied with an IBM 704 computer. Results will be presented for the effect of the various harmonics in the perturbation and of the effect of perturbations in the field gradient. The sixth and tenth harmonics in the perturbation were found to be the most effective which is due to the accelerator having a radial tune $\nu_r = 6.33$ and there being 16 periods around the machine. Some theoretical explanation of the results will be given.

* Supported by the U. S. Atomic Energy Commission.

B5. Measurements of Beam Emittance. R. P. BASTIDE, P. H. ROSE, AND A. B. WITTKOWER, *High Voltage Engineering Corporation.*—The concept of beam emittance[1] which is a direct consequence of basic theorems in Newtonian mechanics seldom has been employed in the study of beam properties in constant potential accelerators. In positive ion accelerators measurements at conjugate points always have proved to be quantitatively difficult. To overcome some of these difficulties, a beam scanner has been developed which has made measurements of beam emittance relatively simple. A thin rotating insulated wire is passed through the beam, and the output signal is presented on the vertical trace of an oscilloscope screen. The horizontal sweep shows the position of the wire. The position of the beam, as well as the beam profile, can be observed for not only charged but also for neutral beams. Results will be presented showing the behavior of beams of different energies ranging from 1 kev to 10 Mev and of intensities ranging from a few millimicroamperes to 30 ma.

[1] D. L. Judd, Ann. Rev. Nuclear Sci. 8, 181 (1958).

B6. Particle Trajectories in Accelerating Tubes. P. H. ROSE AND A. GALEJS, *High Voltage Engineering Corporation.*—Methods and results of a theoretical and experimental attack on the problem of ion beam trajectories in accelerating structures are presented. The electrostatic field has been calculated numerically in a complete accelerating tube applying line relaxation technique on an IBM 704 computer. Individual trajectories have been traced using nonparaxial relativistic ray equations neglecting space-charge which is not important in the case considered. The aperture effect and the dependence of ion trajectories on geometrical parameters, such as finite accelerating electrode thickness and tube diameter, are discussed. The tube acceptance[1] is calculated directly from the transfer matrix obtained from paraxial rays, and the focusing properties of these paraxial rays are compared with calculations based on a first-order approximation.[2] The general applicability of the existing trajectory program to a variety of accelerating systems with minor modifications to the program is demonstrated by results obtained on an Einzel lens. Measurements made using an electrostatic accelerator are used to illustrate the relationship between beam emittance and the corresponding concept of acceptance. The numerical results are used to interpret the experimental material.

[1] P. A. Sturrock, *Static and Dynamic Electron Optics* (Cambridge University Press, New York, 1955).
[2] R. Gans, Z. tech. Physik 18, 41 (1937).

B7. High-Voltage, Low-Ripple Multiplier.* L. D. CHISHOLM, J. L. DUGGAN, AND R. C. MOBLEY, *Louisiana State University.*—A developmental high-voltage multiplier design prototype has been built, tested, and found reliably operable at twice the dc voltage gain per rectifier stage as conventional Cockcroft-Walton multipliers. Basic differences are four: use of a low-duty cycle positive pulse drive voltage, which allows each rectifier to contribute nearly its full rated peak inverse voltage to the dc voltage gain per stage; replacement of rectifiers, not needed for rectification of an almost nonexistent negative drive voltage swing, by passive resistors; use of low-capacitance rf tuned circuits across the ends of similarly tuned filament and anode lines to permit simultaneous independent utilization of these lines for conveying pulse drive and rf filament heating current; a novel rf compensating and pulse canceling arrangement which substantially eliminates output voltage ripple. The ten-stage miniature tube prototype built has successfully operated at output voltages in excess of 250 kv and at output currents up to 500 μa.

* Supported in part by the U. S. Atomic Energy Commission.

Invited Paper

B8. High-Intensity Nanosecond Pulsed Beam. L. CRANBERG, *Los Alamos Scientific Laboratory.* (30 min.)

WEDNESDAY MORNING AT 10:45

New Yorker, Terrace Room

(DAVID HALLIDAY presiding)

Invited Papers in Nuclear Physics

BA1. Nuclear-Structure Studies in Heavy Elements with (d,p) and (d,t) Reactions. B. L. COHEN, *University of Pittsburgh.* (30 min.)

BA2. Analysis of the Structure of Nuclei from Pickup and Stripping Reactions. JAMES RAZ, *Long Island State University.* (30 min.)

WEDNESDAY MORNING AT 10:30

Statler-Hilton, Terrace Ballroom East

(WALTER KOHN presiding)

Electronic Properties of Solids

C1. Range of Excited Electrons in Metals. JOHN J. QUINN, *RCA Laboratories.*—The energies of interaction of a single excited electron with the sea of conduction electrons in a metal is calculated by the self-energy approach.[1] The imaginary part of the electron self-energy can be interpreted in terms of an effective range or mean free path for inelastic collision with the conduction electrons. This range depends strongly on the initial electron energy. Fast electrons, that is those of initial energy greater than the sum of the Fermi energy and the plasma energy of the electron gas, can excite collective oscillations and therefore lose energy very rapidly. The range of slower electrons is determined by the small absorptive part of the dielectric constant of the metal. For electrons of sufficient energy to escape from the metal, the mean free path for an inelastic collision with the conduction electrons appears to be of the order of 10 atomic layers.

[1] J. J. Quinn and R. A. Ferrell, Phys. Rev. 112, 812 (1958).

C2. Calculated Band Structure of Copper. B. SEGALL AND E. L. KREIGER, *General Electric Research Laboratory.*—Recent experiments have determined the Fermi surface of copper in some detail; in particular, it has been established that the surface contacts the hexagonal zone face. It is of considerable interest to see if an a priori band calculation for such a metal, where the d bands are important, would lead to results compatible with observation. An investigation using the Green's[1] function method and two different potentials was carried out. The potentials differed essentially in the manner in which the exchange contribution was computed. Qualitatively the band structures corresponding to the two potentials are similar throughout the d-band and conduction band regions. Large band gaps near the Fermi surface of the order of 4 to 6 ev, with the p level lying lower than the s level at X and L, are found in both cases. The d band which lies above the Γ_1 level has a computed width of about 4 ev. The Fermi surface which can be approximated from the calculated $E(\mathbf{k})$ contacts the zone boundary and in general is in qualitative accord with the experimental determinations.

[1] W. Kohn and N. Rostoker, Phys. Rev. 94, 1111 (1954); J. Korringa, Physica 13, 392 (1947).

C3. Electron Transport Phenomena in Zinc at Low Temperatures.* N. H. ZEBOUNI, C. G. GRENIER, AND J. M. REYNOLDS, *Louisiana State University.*—In order to obtain a complete analysis of the transport phenomena in zinc, all thermomagnetic and galvanomagnetic effects have been measured at 2°K, in magnetic fields up to 13 kgauss. The measurements were taken with either a constant heat current or a constant electric current flowing perpendicular to the hexagonal axis. The magnetic field was parallel to the hexagonal axis. The completeness of the data enables us to calculate the elements of the thermal and electrical conductivity tensors. The Wiedemann-Franz ratio corresponding to both the transverse and longitudinal conductivities were calculated and found to be equal and nearly constant. They differ by less than 5% from the free-electron theory value, over the whole range of the magnetic field. Similarly the elements of the Peltier and thermoelectric tensors were computed. The corresponding elements in both tensors were analyzed in the light of Onsager's reciprocal relation and found to agree with it, within the range of the experimental errors, mainly from the point of view of the amplitude and phase of the de Haas-van Alphen type oscillations exhibited by the measured effects.

* Supported by the Office of Ordnance Research, U. S. Army.

C4. High-Pressure Study of Pressure Dependence of Ettingshausen-Nernst Effect in Zinc.* R. J. DECK, J. M. REYNOLDS, AND C. G. GRENIER, *Louisiana State University.*—A piston and cylinder combination using solid hydrogen as a pressure transmitting medium was constructed for the purpose of studying pressure dependence of galvano- and thermomagnetic effects in zinc up to 2000 atm. The technique involved is that originally developed by Stewart and Swenson[1] for generating high hydrostatic pressure at liquid helium temperatures. The oscillatory Ettingshausen-Nernst effect in zinc has been studied over a range of pressure from 0 to 1500 atm. The period of the oscillations was found to decrease with pressure almost linearly up to 600 atm at which some saturation in the period vs pressure curve started to take place. No evidence of the oscillatory dependence of the period as a function of pressure, which was reported by Verkin and Dmitrenko,[2] was observed.

* Supported by the Office of Ordnance Research, U. S. Army.
[1] J. W. Stewart and C. A. Swenson, Phys. Rev. 94, 1069 (1954).
[2] B. I. Verkin and I. M. Dmitrenko, Soviet Phys.—Doklady 4, 118 (1959).

C5. Electrical Resistivity and Thermoelectric Power of Desorbed Palladium-Hydrogen. A. I. SCHINDLER, *U. S. Naval Research Laboratory,* R. J. SMITH, *National Aeronautics and Space Administration,* AND E. W. KAMMER, *U. S. Naval Research Laboratory.*—Electrolytic charging with hydrogen up to a hydrogen-to-palladium atom ratio of 0.6 increases the lattice parameter of palladium by approximately 3%. We have

observed that, if the sample is then desorbed by heating in vacuum, or by oxidation, there remains a residual expansion in the lattice parameter of one part in four thousand. To determine the effects of the expanded lattice upon the electrical properties, measurements of the electrical resistivity and thermoelectric power have been made as a function of temperature on desorbed palladium-hydrogen. The electrical resistivity data indicate that the charging and subsequent desorbing of the hydrogen causes strains in the palladium lattice which increase the residual resistivity (at 4°K) by 5.3%. However, this same treatment decreases the value of $d\rho/dT$ between 4°K and 300°K so that the initial increase in the resistivity is more than compensated by the $(d\rho/dT)\Delta T$ term, and at 300°K the resistivity of the desorbed palladium is lower than that of pure annealed palladium. These results can be described in terms of a Debye temperature change of +15°K. Also the decrease in $d\rho/dT$ for the desorbed specimens would indicate a change in the electronic configuration, especially the occupation of the *s* and *d* density of states, thus suggesting a change in the magnetic characteristics of the specimens.

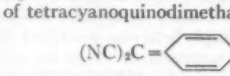
C6. Transition Radiation from Metal Slabs. EDWARD A. STERN, *University of Maryland.*—It has been predicted that electrons passing through thin metal foils will excite plasma oscillations which then radiate electromagnetic photons[1] at the plasma frequency. This phenomena is considered from the viewpoint of transition radiation[2] from metal slabs. Electrons passing from one medium to another of differing dielectric constant will radiate because of the sudden change in electromagnetic fields surrounding the electron as it makes the transition; hence the name transition radiation. A peak in the transition radiation at the plasma frequency from thin metal foils is found. In addition, expressions are found for the radiation at frequencies other than the plasma frequency and the angular distribution of the radiation.

[1] R. A. Ferrell, Phys. Rev. 111, 1214 (1958).
[2] I. Frank and V. Ginsburg, J. Phys. (U.S.S.R.) 9, 353 (1945).

C7. Reflectivity of Graphite from 4.4 to 14.4 ev.* J. R. NELSON AND W. C. CROCKER, *General Dynamics Corporation.*—A large absorption peak is seen in the absolute normal incidence (5 deg) reflectivity of a single crystal (face is perpendicular to the *z* axis) of pyrolytic graphite in the far ultraviolet. This peak is centered at 2400 A (5.17 ev) and is quite broad. In addition, there is a broad peak of low magnitude centered at 975 A (12.7 ev) where a large absorption peak occurs in diamond (110 face).[1] For the 2400-A peak there is a correlation with the work of Taft and Apker,[2] who have noticed a sharp increase in the photoelectric yield in polycrystalline graphite at about 2600 A.

* This research is supported in part by the Advanced Research Projects Agency through the U. S. Air Force Cambridge Research Center, Air Research and Development Command.
[1] J. R. Nelson and W. C. Crocker, Bull. Am. Phys. Soc. Ser. II, 5, 431 (1960).
[2] E. Taft and L. Apker, Phys. Rev. 99, 1831 (1955).

C8. A New Class of High-Conductivity Organic Solids. R. G. KEPLER, P. E. BIERSTEDT, AND R. E. MERRIFIELD, *E. I. du Pont de Nemours and Company.*—A new class of highly conducting organic solids was recently discovered in this laboratory.[1] These materials are salts based on the anion-radical of tetracyanoquinodimethan (TCNQ):



The highest conductivity materials (100 Ω^{-1} cm^{-1}) exhibit temperature-independent paramagnetism, indicating that the charge carriers are degenerate. In the less conductive compounds the charge carriers appear to be localized with their mobility depending exponentially on temperature. Magnetic susceptibility measurements show that in the less conductive materials the extra electrons on the TCNQ molecules are paired up in quasi-molecular states with a singlet ground state and a triplet state lying a small energy above. The conductivity of these materials is highly anisotropic. For example, in one material the room temperature conductivities are 4.0, 0.05, and 0.001 Ω^{-1} cm^{-1} in the three principal crystal directions.

[1] D. S. Acker *et al.*, J. Am. Chem. Soc. (to be published).

WEDNESDAY MORNING AT 11:00

Statler-Hilton, Terrace Lounge

(P. H. FANG presiding)

Ferroelectricity

D1. $Pb(Sc_{0.5}Nb_{0.5})_xM_{1-x}O_3$ and $Pb(Sc_{0.5}Ta_{0.5})_xM_{1-x}O_3$, Ferroelectric Solid Solutions Possessing Large Spontaneous Polarizations. V. J. JOHNSON, M. W. VALENTA, J. E. DOUGHERTY, AND R. M. DOUGLASS, *Los Alamos Scientific Laboratory,* AND JOHN GJEVRE, *University of North Dakota.*—Perovskite-type solid solution systems, having the general formula $Pb(Sc_{0.5}Nb_{0.5})_xM_{1-x}O_3$, where M is a four-valent metal ion of group IVB of the periodic table, were synthesized in ceramic form. The maximum room temperature spontaneous polarization that was observed is about 23 μcoul/cm^2; spontaneous polarizations were obtained from hysteresis loops observed at 60 cps with the aid of an ordinary Sawyer-Tower circuit. The Curie temperature and spontaneous polarization tend to decrease in value, correspondingly, as Ti is replaced by Zr and Zr by Hf. An increase in the concentration of a particular M increases the Curie temperature of the corresponding solid solution system. The systems $Pb(Sc_{0.5}Ta_{0.5})_x$ $\times M_{1-x}O_3$ behave similarly to the above and also will be discussed.

D2. Thermal Conductivity of Triglycine Sulfate near its Ferroelectric Curie Point. FRED C. UNTERLEITNER, *General Dynamics Corporation, Rochester.*—A method for measuring the diffusivity of materials with strongly temperature-dependent dielectric constants has been devised which requires temperature gradients of only ~0.02°C across the sample in a typical case. This permits the measurement of diffusivity in a temperature range where it undergoes rapid variations. The first material studied by this means was triglycine sulfate near its ferroelectric transition point at 49°C. The diffusivity of several *b* axis plates was measured in the temperature range 40°C to 60°C. The specific heat measurements of Hoshino *et al.*[1] were used to obtain the thermal conductivity *k*. Above the Curie point, *k* is independent of temperature within experimental error, having a value $k = 1.1 \times 10^{-3}$ cal/g cm°C. Below

the transition, k drops sharply to about 2×10^{-4}, then rises again to 8×10^{-4} at 40°C. The application of a dc electric field reduces the magnitude of the drop.

[1] S. Hoshino, T. Mitsui, F. Jona, and R. Pepinsky, Phys. Rev. **107**, 1255 (1957).

D3. Field Dependence of the Dielectric Constant in Strontium Titanate.* G. RUPPRECHT, *Raytheon Company.*—The nonlinear properties of $SrTiO_3$ single crystals have been investigated above the Curie temperature between −180°C and room temperature over a frequency range from 1000 cps to 26 kMc/sec. The dielectric constant ϵ is independent of frequency to at least 37 kMc/sec and follows a Curie-Weiss law. The observed change of the dielectric constant $\Delta\epsilon$ is proportional to the square of the external electric field E and to the fourth power of the dielectric constant ϵ. The constant of proportionality in this relation is independent of frequency but depends upon the crystallographic direction. Microwave data on three different single crystals will be presented. The external dc electric field and the probing microwave field are parallel in these experiments and have been chosen to lie in the [100], [110], and [111] directions. The results which are reproducible within a few percent, from one crystal to the next, will be compared with Slater's theory of ferroelectricity. Small deviations from the simple behavior described above are found at the low end of the temperature range for sufficiently high electric fields, indicating the contribution of higher order terms. The measuring technique will be mentioned.

* This work has been supported partially by the U. S. Air Force Cambridge Research Laboratory.

D4. Microwave Losses in Strontium Titanate.* R. O. BELL AND G. RUPPRECHT, *Raytheon Company.*—The microwave loss of single crystal $SrTiO_3$ has been measured from 3 kMc/sec to 37 kMc/sec over a temperature range from 80°K to 475°K. The temperature dependence of the loss tangent shows a minimum at 140°K or about 60° above the Curie temperature. At temperatures below the minimum the losses show an appreciable increase, while above the minimum the increase is more gentle. The loss tangent at the minimum was found to be proportional to the frequency with a value of 1.0×10^{-3} at 20 kMc/sec. With a dc electric field applied parallel to the microwave field, the loss tangent shows an increase. The field-dependent part of the loss tangent, $\tan\delta_F$ (up to 7 kMc/sec), is proportional to the square of the electric field, to the frequency of the microwave field, and to ϵ^n where n lies between 4 and 5. A theoretical explanation for the behavior of the microwave losses has been prepared by B. D. Silverman.

* This work has been supported partially by the U. S. Air Force Cambridge Research Laboratory.

D5. Interpretation of Microwave Absorption Measurements in Crystalline Strontium Titanate. B. D. SILVERMAN, *Raytheon Company.*—The microwave loss tangent of crystalline strontium titanate has been investigated above the transition temperature by employing a linear chain model of a ferroelectric. The model consists of oxygen and titanium ions coupled along chains in the [1,0,0], [0,1,0], and [0,0,1] directions on the unit cell. The microwave radiation field excites the transverse mode of uniform polarization which decays by transferring energy to lattice thermal modes. The temperature dependence of the loss tangent due to damping of the polarization mode by an nth order anharmonicity is found to be $T^{n-2}/(T-T_c)$. Impurity damping yields a dependence of the form $1/(T-T_c)$, where T_c is the transition temperature. These results will be compared with experiment. The behavior of the loss tangent for a sample subjected to a biasing field also will be discussed.

* This work has been partially supported by the U. S. Air Force Cambridge Research Laboratory.

WEDNESDAY MORNING AT 10:15

Martinique, Empress Josephine Room

(R. J. GLAUBER presiding)

Theoretical Physics I: Atomic Physics

DA1. Repulsion of Energy Levels in Complex Atomic Spectra. R. E. TREES, *National Bureau of Standards.*—"The repulsion of energy levels" in the low even configurations of atomic spectra has been shown to be fully developed for third long period spectra and in an intermediate stage of development for second long period spectra.[1] This was demonstrated by calculating positions of energy levels from matrices. By carefully selecting and combining observed data from several spectra, these conclusions were verified from the observed data.

[1] R. E. Trees (submitted to Phys. Rev.).

DA2. Ionization Potential of Atoms. PETER WALSH, *Westinghouse Lamp Division.*—The use of interelectron coordinates in atomic wave functions[1-3] was applied to calculating the ionization potential of neutral atoms in zero order. By introducing interelectron coordinates connecting the electron to be removed from the nth orbit and the N remaining electrons of opposite spin, the corresponding singularities in the interelectron potential are treated correctly. The singularities arising from interaction with electrons of the same spin are nullified by antisymmetrizing the wave function. These latter electrons are further allowed for by reducing the nuclear charge Z to $Z-N-1$. This means, however, that the electron-nucleus potential is not treated exactly at its singularity. The conditions, that proper shielding occur and that the perturbation in the problem vanish asymptotically, yield the ionization potential: $E=-(N+1)/2n^2$ (a. u.). This result is valid for atoms whose last electron is not penetrating, especially the rare gases, and for the lighter atoms. For atoms up to Ne, the average deviation from the experimental values is 10%.

[1] P. Pluvinage, Ann. phys. 12, 10 (1950).
[2] M. Kelly and L. Spruch, Phys. Rev. 116, 911 (1959).
[3] P. Walsh and S. Borowitz, Phys. Rev. 115, 1206 (1959); 119, 1274 (1960).

DA3. Relativistic Theory of Many-Electron Atoms.* DAVID LAYZER AND JOHN BAHCALL,† *Harvard College Observatory.*—We have developed a relativistic generalization of the Z-dependent approximation scheme for many-electron atoms recently described by the senior author.[1] In contrast with current methods for dealing with level shifts and term splitting, the new scheme makes possible a unified description of relativistic effects over the entire range of the coupling parameter $\alpha^2Z_{eff}^2$. The fractional errors of relativistic energy changes

predicted in first approximation with the new scheme should be of the order Z_{eff}^{-2} and $\alpha \log \alpha$. In order to achieve this accuracy over the entire range of the coupling parameter, one needs to replace Breit's formulas for the relativistic interaction between two electrons in LS and jj coupling by a more elaborate formula, derived from quantum electrodynamics, which reduces to Breit's formulas in the two extreme cases. As in the nonrelativistic scheme, all interactions that connect states belonging to the same complex (i. e., the same principal quantum numbers and the same parity) are taken into account in the first approximation. In this approximation the screening parameters neither affect nor are affected by relativistic energy changes.

* Supported in part by the National Science Foundation.
† Present address: Physics Department, Indiana University, Bloomington, Indiana.
[1] D. Layzer, Ann. Phys. **8**, 271 (1959).

DA4. Relativistic Level Shifts in Two- and Three-Electron Atoms.* JOHN BAHCALL† AND DAVID LAYZER, *Harvard College Observatory*.—By use of the theory mentioned in the preceding abstract, we have calculated relativistic level shifts for the ground states of atoms in the isoelectronic sequences headed by helium and lithium. Because the energy matrices $H_{(n)pJ}$ are diagonal in both cases, the ground-state energies can be expanded in double series $\Sigma_{m,n} E_{mn} Z^{-m} \epsilon^n$, $\epsilon = (\alpha Z)^2$. The coefficients E_{0r} $(r = 1, 2, \cdots)$ can be obtained directly from the Bohr-Sommerfeld formula; E_{10} is given by the nonrelativistic theory, which also supplies approximate values for the coefficients E_{r0} with $r \geq 2$. The relativistic theory is needed to evaluate the coefficients E_{1r} with $r \geq 1$. As for E_{mn} with both $m > 1$ and $n > 0$, they cannot be accurately evaluated by means of existing methods. Our calculations are based on the approximate formula $E = W_2 Z^2 + W_1 Z + W_0 + W_4 \alpha^2 Z^4 + W_5 \alpha^2 Z^3$, in which only the value of W_5 is approximate. Predicted ionization potentials in both sequences agree very well with experiment at large values of Z when an empirical correction to W_5 is introduced. In the helium sequence the residuals agree qualitatively with the predicted Lamb shift, though the magnitude of the experimental errors prevents a definitive statement. We are currently evaluating relativistic effects in four-electron systems.

* Supported in part by the National Science Foundation.
† Present address: Physics Department, Indiana University, Bloomington, Indiana.

DA5. Lamb Shift Excitation Energy in the Metastable States of the Helium Atom.* K. S. SUH AND M. H. ZAIDI, *Cornell University*.—In order to reduce the discrepancy between the experimental and the theoretical ionization energy values of the metastable $2^{1,3}S$ states of the helium atom, it is necessary to include the radiative corrections. The most important contributions to the average excitation energy are from transitions to $(2s$; discrete, continuous $p)^{1,3}P$ states, which was previously pointed out by Dalgarno and Kingston, while those from transitions to $(1s, 3s$; discrete, continuous $p)^{1,3}P$ states are still large and even the $(\geq 4s$; continuous $p)^{1,3}P$ contributions are by no means negligible. To estimate the error arising from our using approximate values of the oscillator strengths, we use sum rules and a modified Pekeris method. The uncertainty in the Lamb shift correction stems mainly from the calculation of the average excitation energy. The radiative correction terms of Kabir and Salpeter cancel and leave only small contribution to the $2^{1,3}S$ levels, so that the rest of the terms, including Sucher's, may be important. Numerical results as well as the general feature of the problem will be discussed.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

DA6. Perturbation Energy Coefficients of the Two- and Three-Electron Isoelectronic Series from Variational Wave Functions.* CHARLES W. SCHERR AND JEREMIAH N. SILVERMAN, *University of Texas*.—The second- and higher-order nonrelativistic perturbation energy coefficients of the two- and three-electron isoelectronic ionic series have been recovered from variationally obtained nonrelativistic energies for these series using the best data available.[1] The method was originally developed by Scherr, Silverman, and Matsen[2] for application to experimental data and is based on the perturbation series expansion of nonrelativistic energies in descending powers of the nuclear charge. The second- and third-order perturbation energy coefficients of the helium sequence so obtained are in good agreement with the results obtained by Hylleraas[3] in another manner while the remaining coefficients are not reported accurately elsewhere. The coefficients permit very accurate extrapolations to systems with larger nuclear charge. In addition, the perturbation expansion coefficients of the mass-polarization, relativistic, and Lamb-shift corrections for the helium sequence have been recovered by the same procedure.

* This research was supported in part by the Robert A. Welch Foundation of Houston, Texas.
[1] C. L. Pekeris, Phys. Rev. **112**, 1649 (1958); **115**, 1216 (1959); A. Weiss (private communication).
[2] C. W. Scherr, J. N. Silverman, and F. A. Matsen, Bull. Am. Phys. Soc. Ser. II, **5**, 433 (1960).
[3] E. A. Hylleraas and J. Midtdal, Phys. Rev. **103**, 829 (1956); **109**, 1013 (1958).

DA7. Approximate Born Cross Sections for Inelastic Scattering of Electrons by Hydrogen Atoms in High Quantum States.* GERARD C. MCCOYD AND S. N. MILFORD, *St. John's University*.—In an attempt to find approximate values of the Born cross section for high quantum states n, the cross section is computed for the transition $n = 10$, $l = 9 \rightarrow n' = 11$, $l' = 10$ at incident electron energies of 1124 and 18 000 ev. The values of the Bethe approximation cutoff momentum κ_c are then compared for the known Born cross sections for strong optically allowed transitions arising from the $n = 1, 2, 3, 4, 5, 10$ levels. Interpolation should give reasonably accurate Bethe (dipole) cross sections for $n = 6, 7, 8, 9$. As shown in earlier[1] work, the Bethe cross section fits the Born to within 10% down to energies approximately 15 times threshold. A comparison of the shapes of all strong allowed transitions suggests that all such transitions have the same general shape down to about 10 times threshold.

* Supported by the U. S. Air Force Office of Scientific Research and Office of Naval Research.
[1] Gerard C. McCoyd, S. N. Milford, and John J. Wahl, Phys. Rev. **119**, 149–153 (1960); Leonard Fisher, S. N. Milford, Frank R. Pomilla, Phys. Rev. **119**, 153–155 (1960); S. N. Milford, John J. Morrissey, and Joseph H. Scanlon, Phys. Rev. **120**, 1715 (1960).

DA8. Approximate Cross Sections for Forbidden Inelastic Collisions of Electrons with Atoms.* JOSEPH H. SCANLON AND S. N. MILFORD, *St. John's University*.—The form of the cross section σ at its maximum is combined with the high-energy Bethe expression to obtain the momentum cutoff in terms of ϵ_1, the energy at which the maximum occurs. The multipole expansion then provides a simple approximate formula for the cross section, in the region $\epsilon > \epsilon_1$, in terms of the quadrupole moment determined from experiment or computation; the threshold shape is adopted for $\epsilon < \epsilon_1$. The curve for $\sigma(\epsilon_1)$ is found to cross the Born approximation curve within 10% of the Born maxima for several forbidden transitions in hydrogen. With an appropriate choice for ϵ_1, the simple $\sigma(\epsilon)$ formula satisfactorily reproduces the Born values for the $\Delta n = 1$ transitions considered. Unlike the allowed transitions,[1] however, for other cases acceptable agreement is not obtained.

* This work was supported by the U. S. Air Force Office of Scientific Research and the Office of Naval Research.
[1] S. N. Milford, Astrophys. J. **131**, 407 (1960).

DA9. Scattering of Electrons by Heavy Atoms.* MARVIN H. MITTLEMAN, *Lawrence Radiation Laboratory, Livermore*, AND

KENNETH M. WATSON, *University of California, Berkeley.*—We have formulated the problem of the elastic scattering of electrons from atoms in terms of an equivalent potential. While we have given a prescription for the exact determination of this potential in terms of the wave functions of the atom, it is only feasible to do so approximately. Our approximation is an expansion in the number of virtual inelastic scatterings. We allow only one such scattering and approximate the resulting dispersive part by the well-known polarization potential. Inclusion of the Pauli principle between the incoming electron and the bound ones modifies the potential in two ways: First, it introduces the usual exchange potential and, second, it requires that the incoming electron wave function be orthogonal to all the bound state electrons. Both of these effects make the potential nonlocal. The final potential is uniquely determined in terms of the properties of the atom. That is, we have no adjustable parameters. Nevertheless, we have included such parameters in it for the purpose of determining the effect of each part of the potential separately. The integral-differential scattering equation has been programmed for the IBM 709 for a general atom.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

DA10. Group-Theoretical Treatment of Time- and Energy-Dependent Multiple Scattering, with Application to the Slowing Down of Neutrons. E. GUTH AND E. INÖNÜ, *Oak Ridge National Laboratory.*—Wigner developed a group-theoretical method for those problems of multiple scattering in which the elementary scattering law is invariant under a group of transformations. The integral transforms, used in more standard treatments for the reduction of convolutions, come in here more naturally through the representations of the groups of transformations. Wigner's work is extended here to include the time-dependent slowing down of neutrons. In this case a group of linear transformations comes in which does not yield orthogonality. Nevertheless, it is possible to determine all positive time moments of the distribution function and from them the distribution function itself. The conditions for the existence of the group are that the total scattering cross section is proportional to v^γ (γ is any real number) and that either the ratio of absorption to scattering cross section is constant (including zero) or that the absorption cross section varies as $1/v$. Moreover, it is assumed that the angular dependence can be anisotropic but does not depend on energy in the center-of-mass system. For a special case, our solution reduces to Waller's recent exact expression.

WEDNESDAY AFTERNOON AT 1:45

Martinique, Empress Josephine Room

(T. H. BERLIN presiding)

Theoretical Physics II: Statistical Mechanics and Many-Body Problems

E1. Correction to the Debye-Hückel Theory.* STEPHEN G. BRUSH AND JOHN G. TRULIO, *Lawrence Radiation Laboratory, Livermore.*—The equation of state of a classical ionized system has been calculated at high temperatures and low densities, using the diagram expansion theory developed by Abe and others.[1] For a one-component system (point electrons with a uniform background of positive charge) the results may be compared with those recently obtained by Bowers and Salpeter[2] and with an approximate formula derived by those authors and also by Abe. For the two-component system the "soft" potential $\pm(e^2/r)(1-e^{-\gamma r})$ has been used to avoid the divergence at the origin; with an appropriate choice of γ the classical and quantum mechanical ring terms are then the same.[3]

* Supported by the U. S. Atomic Energy Commission.
[1] R. Abe, Progr. Theoret. Phys. (Kyoto) **22**, 213 (1959); E. Meeron, J. Chem. Phys. **28**, 630 (1958); Phys. Fluids **1**, 139 (1958); H. L. Friedman, Mol. Phys. **2**, 23 (1959); J. Chem. Phys. **32**, 1134, 1351 (1960).
[2] D. L. Bowers and E. E. Salpeter, Phys. Rev. **119**, 1180 (1960).
[3] H. DeWitt (to be published).

E2. Quantum Mechanical Modification of the Meeron Nodal Expansion. HUGH DEWITT, *Lawrence Radiation Laboratory, Livermore.*—The equation of state of a classical electron gas may be calculated for low density from the nodal expansion developed by Meeron.[1] The analogous quantum theory so far has been carried out only for the ring diagrams.[2] In order to get some estimate of quantum effects in the nodal expansion, a modified Coulomb potential has been used; the form is $(e^2/r)(1-\exp-\lambda_{th}r)$, where $\lambda_{th}=\hbar/(2mkT)^{\frac{1}{2}}$ is the thermal deBroglie wavelength. This modified potential is suggested by the evaluation of the exact quantum theory of the ring diagrams.[3] For the electron gas, which has a classical limit, the quantum effects thus calculated are small. For a two-component gas of point charges, however, the quantum effects are of major importance, since the modified potential cuts off the divergence at $r=0$ in the terms of the nodal expansion. Analytical results using this potential will be given.

[1] E. Meeron, Phys. Fluids **1**, 139 (1958).
[2] A. Sakakura, Ph.D. thesis, University of Colorado (1960).
[3] H. E. DeWitt, Bull. Am. Phys. Soc. Ser. II, **5**, 7 (1960).

E3. Disturbances of Open Systems. ABNER SHIMONY, *M.I.T.*, AND JOEL L. LEBOWITZ,* *Yeshiva University.*—We have applied the response function method of Kubo[1] to an open system in contact with a heat reservoir and acted upon by an external field. We find that under certain general conditions the linear response of the system may be expressed in a form similar to that obtained by Kubo for a closed system. A corollary to this is a fluctuation-dissipation theorem relating the heat flow into the reservoir to an auto-correlation function in the system unperturbed by an external field. Another result obtained by this method concerns the stationary nonequilibrium state of a system in contact with several heat and particle reservoirs at slightly different temperatures and chemical potentials. Here we find an expression for the deviation of the stationary ensemble representing this system from its equilibrium value. This enables us also to express the Onsager coefficients relating the heat and particle fluxes from the reservoirs to the deviations in the reservoir parameters, as a correlation function in the equilibrium system, and exhibits their symmetry.

* Supported by the U. S. Air Force Office of Scientific Research.
[1] R. Kubo, J. Phys. Soc. Japan **12**, 570 (1957).

E4. The Grand Partition Function as Average of a Functional of Gaussian Random Functions.* R. HIROTA, *Northwestern University* (introduced by A. J. F. Siegert).—It is known that the grand partition function for a system of particles interacting by pair interaction is the average of the grand partition function for noninteracting particles in a common

external Gaussian random field which is in general complex valued and whose statistical properties are determined by the pair interaction potential. Another expression for the grand partition function as the average of a functional of Gaussian random functions is given by

$$\mathcal{Q}_V(z) = \mathcal{Q}_V^{(0)}(z)\left\langle \exp\left(-\frac{1}{2}\int \psi^*(x)\psi^*(x')v(x-x')\psi(x')\psi(x)d^4x'd^4x\right)\right\rangle_{av},$$

where $\psi(x)$ is a Gaussian random function of position and reciprocal temperature and is determined by its covariance $\langle\psi^*(x)\psi(x')\rangle_{av}$ which is the one-body free particle Green's function. The derivation is based on the fact that the Matsubara average of a T product of free Bose field operators is expressed as a sum over all possible contractions in a way which is entirely analogous to the expression for the average of a product of Gaussian random functions.

* Based on work performed under Office of Naval Research contract.

E5. Green's Function for Liouville Equation in Quantum Mechanical Phase Space. GEORGE J. YEVICK, *Stevens Institute of Technology*, AND J. K. PERCUS, *New York University*.—A knowledge of the Green's function for the Liouville equation in phase space is significant for achieving an insight into the mechanism of phase space motion for quantum-mechanical systems. For the Liouville equation in quantum mechanical phase space, the Liouville operator can be regarded as the Hamiltonian for a "diffusion-like" equation. The long-time Green's function is difficult to compute although, in a number of simple problems, it can be determined by extrapolation from short time. The short-time Green's function can be obtained by a modification of the Feynman path integral technique. To use this method, it is necessary to find the Lagrangian corresponding to the above Hamiltonian. This is not a trivial problem. It is possible to construct an effective potential in terms of which the Lagrangian may be written explicitly. This potential in fact is nonlocal in phase space requiring transitions in the imaginary direction of the complex plane. There are several ways of interpreting this pecuilar type of nonlocality, ranging from the use of modified commutation relations in quantum mechanics to the introduction of a subsidiary or "ghost" phase space.

E6. Inviscid Flow in a Many-Boson System. J. K. PERCUS, *New York University*.—The ground state of a uniform many-boson system may be characterized by its property of vanishing under the action of plane wave longitudinal and transverse phonon annihilators. A reasonable form for these annihilators may be obtained by extrapolating from a strong-coupled lattice model. If the transverse frequencies are all zero, the system will be called inviscid. Both velocity and density variations may be appended to the ground state by a simple multiplicative transformation. Under the above conditions, this modified wave function is an exact solution of the dynamic Schrödinger equation if the macroscopic density and velocity are related by (1) conservation of mass and (2) conservation of momentum with a special nonlocal equation of state. The foregoing readily accommodates to application of an external potential. Several classes of irrotational as well as vortex flows may be recognized and their dependence on the phonon excitation spectrum assessed. Extension to states of low phonon excitation and also to statistical states initially in thermal equilibrium will be discussed.

E7. Low-Temperature Fermi Systems.* FRANZ MOHLING, *Cornell University*.—By use of the quantum statistical method of Lee and Yang, the momentum distribution and energy per particle of a low-temperature system of particles have been studied. For a Fermi gas with short-range interactions, it is shown that, in order to determine the very low-temperature momentum distribution, two coupled integral equations must be considered, one in momentum variables, due to Lee and Yang, and the other in temperature variables. It is then shown that the dominant low-temperature behavior of the momentum distribution can be extracted in terms of a certain function $\nu'(k)$. Moreover, at $T=0$, it is shown to third order in the scattering parameters of the interaction that the function $\nu'(k)$ is equal to the free particle momentum distribution. Finally, the energy and other thermodynamic quantities are expressed in terms of $\nu'(k)$. An expansion of the energy per particle in powers of the two-body reaction matrix is proposed, and it is shown for the ground state nuclear many-body problem that the leading terms in this expansion are in agreement with those given by the Bethe-Goldstone equation.

* Supported in part by the U. S. Atomic Energy Commission and the Office of Naval Research.

E8. Motion of Foreign Atoms in a Boson Fluid. E. P. GROSS, *Brandeis University*, AND C. R. WILLIS, *Boston University*.—In a recent paper by one of us[1] a general theory of the motion of foreign atoms in a boson fluid was formulated. In this paper a formal analogy between the electron lattice problem and the foreign atom was demonstrated. This suggested that, in addition to the intermediate coupling solution which corresponds to the Feynman solution, one should look for a solution in the strong coupling limit, i.e., the adiabatic limit. We have done this for various models. For a model of the boson fluid we have taken the Hamiltonian derived by Bogoliubov.[2] We have considered both theoretical and experimental curves for the structure function, i.e., the Fourier transform of the pair distribution function. We have computed the energy for these various models both in the intermediate and strong coupling limits.

[1] E. P. Gross, Ann. Phys. 9, 292 (1960).
[2] N. N. Bogoliubov and D. N. Zubarev, J. Exptl. Theoret. Phys. (U.S.S.R.) 28, 129 (1955).

E9. N-Dependence of Low-Order Distribution Functions. JOEL L. LEBOWITZ,* *Yeshiva University*, AND J. K. PERCUS, *New York University*.—One of the features characterizing a fluid is the existence of a finite correlation length λ. For molecular separations large compared to λ the low-order Ursell functions F_n approach values which are of $o(N)$: in a closed system containing N particles. We have found a simple general expression for the N^{-1} term in this asymptotic region and used it to prove the local nature of the low-order distributions in an inhomogeneous system. For systems with periodic boundary conditions there are no shape-dependent corrections to F_2, and the N^{-1} correction applies also to small separations. This should be detectable, in principle, in the recent machine computations of the radial distribution function for a wide range of values of N. The asymptotic value of the radial distribution function also may be used to obtain the high-temperature equation of state of a fluid consisting of particles having a hard core and a wide shallow square well potential.

* Supported by the U. S. Air Force Office of Scientific Research.

E10. Mobility of Ions in a System of Interacting Bose Particles.* R. ABE AND K. AIZU, *Northwestern University*.—The average velocity of ions moving in a system of interacting Bose particles subject to an external electric field is calculated by means of the Boltzmann equation. The interaction Hamiltonian which describes the ion-phonon scattering processes is obtained by the use of the Bogoliubov transformation. A simple application of perturbation theory yields an explicit form of the collision operator for the scattering of the ion by phonons and enables one to set up the Boltzmann equation describing the motion of the ions. The solution of this equation is obtained by applying a variation principle, and the tempera-

ture dependence of the ion mobility is shown to be T^{-4} at very low temperatures. A comparison with the experimental results in liquid helium is given, and the ion mobility in a Fermi system is discussed.

* Work supported by the Office of Naval Research and the National Science Foundation.

E11. Perturbative Treatment of Pairing Interactions in Many-Fermion Systems.* MARK BOLSTERLI, *University of Minnesota*.—A canonical transformation is introduced to simplify the commutation relations of the operators which create and annihilate Fermion pairs. The transformed pair creation and annihilation operators have the standard single-Fermion anti-commutation relations; at the same time they commute with the operator for the total number of particles. The transformed pairing Hamiltonian is diagonalized to lowest order in the interaction; the eigenvalue equation contains both the weak and strong coupling limits.

* This work supported in part by the U. S. Atomic Energy Commission.

E12. Variational Method for the Quantum Statistics of Interacting Particles. M. GIRARDEAU, *Boeing Scientific Research Laboratories*.—A theorem due to Peierls[1] implies that one obtains a lower bound to the quantum-statistical partition function, and hence an upper bound to the thermodynamic potential, if in evaluating the partition function one replaces the Hamiltonian by its diagonal part in any representation. We have developed a variational method for calculating the thermodynamic properties of many-body systems with pairwise interactions by choosing a representation in terms of quasiparticles related to free particles by a linear canonical transformation involving variational parameters (arbitrary functions). It is necessary to treat the diagonal part of the interaction between quasiparticles exactly in order to obtain an upper bound to the thermodynamic potential; this has been done by summing those Bloch-deDominicis graphs[2] which contribute in the limit of an infinite system. An illustrative application to the BCS mode of superconductivity has been worked out. Our theory reduces to theirs both at zero temperature and at the transition, but we obtain small but nonvanishing corrections at intermediate temperatures due to quasiparticle interactions. In this connection, we discuss a weak point in the BZT "proof" of the exactness of the BCS thermodynamics.

[1] R. E. Peierls, Phys. Rev. **54**, 918 (1938).
[2] C. Bloch and C. deDominicis, Nuclear Phys. **7**, 459 (1958).

E13. Statistical Mechanics of Liquids Composed of Polarizable Molecules. A. ISIHARA, *Polytechnic Institute of Brooklyn*, AND RUSSELL V. HANKS, *Boeing Scientific Research Laboratories*.—The many-body problem concerning the calculation of the susceptibility of liquids is considered. It is assumed that our system is composed of nonpolar molecules, and the external field induces dipoles proportional to it, the proportional constant being the polarizability. The induced dipole moment in the ith molecule is determined not only by the external field but also by the internal field due to the induced dipoles in the other molecules. The induced dipole-dipole interactions are taken into consideration in addition to the ordinary intermolecular forces, and the diagrams associated with the susceptibility are examined.

E14. Short-Range Time-Dependent Correlations in the Hard Sphere Gas.* FRANK A. HORRIGAN, *Harvard University*.—By using the Martin-Schwinger Green's function techniques, a short-range, short-time approximation has been developed for the time-dependent density correlation function of the hard sphere gas. Under the assumption of low density and short-range forces, the correlations between three or more particles may be neglected, leading to a generalization of the T matrix equation of scattering theory. The problem then can be reduced to that of ordinary two-particle scattering by expanding the temperature effects in powers of the fugacity in the high-temperature limit. The terms appropriate to the short-range, short-time region describe the familiar "hole," due to the impenetrability of the hard spheres, and additional correlations due to the many-particle nature of the system. The way in which these correlations dissolve with time is shown explicitly. The correlation functions are used to discuss the scattering of slow neutrons by the hard sphere gas.

* Supported in part by the U. S. Air Force Office of Scientific Research.

E15. Convergence of Linked Cluster Expansions.* LEON N. COOPER,† *Brown University*.—A strong-coupled, many-Fermion system defined by the Hamiltonian

$$H = gV = g/2 \sum_{\substack{k,\,k',\,q\in S \\ \sigma,\sigma'}} C^{+}_{k+q,\sigma} C^{+}_{k'-q,\sigma'} C_{k',\sigma'} C_{k,\sigma} V(q),$$

where S is a thin shell about the Fermi surface, has been analyzed in order to obtain information concerning a many-Fermion system which is not dependent upon assumptions about the convergence of power series expansions or on partial summations of infinite series. It is shown that the linked cluster expansion of the vacuum expectation value of the resolvent operator[1]

$$\left\langle \varphi_0 \left| \frac{1}{gV - Z} \right| \varphi_0 \right\rangle_c = -\frac{1}{Z} \sum_{n=0}^{\infty} \left(\frac{g}{Z}\right)^n \langle \varphi_0 | V^n | \varphi_0 \rangle_c$$

has a zero radius of convergence as a power series expansion in the coupling constant. This is so in spite of the fact that the nonlinked expansion has a finite radius of convergence. Alternate convergent linked cluster expansions have been found.

* Supported in part by the U. S. Atomic Energy Commission.
† Alfred P. Sloan Foundation Fellow.
[1] N. M. Hugenholtz, Physica **XXIII**, 481 (1957).

WEDNESDAY AFTERNOON AT 2:00

New Yorker, Grand Ballroom

(J. A. WHEELER presiding)

Invited Papers on Nuclear Fission

EA1. Fission and Nuclear Structure. J. J. GRIFFIN, *Los Alamos Scientific Laboratory*. (30 min.)

EA2. Neutron Yield from Individual Fission Fragments. JAMES TERRELL, *Los Alamos Scientific Laboratory*. (30 min.)

EA3. Fine Structure in the Fission Prompt Mass Yields and the Total Kinetic Energy near Symmetry. J. C. D. MILTON, *Lawrence Radiation Laboratory and Chalk River Laboratories*. (30 min.)

EA4. Fission Measurements by Use of Solid-State Dectectors. E. MELKONIAN, *Columbia University*. (30 min.)

WEDNESDAY AFTERNOON AT 2:00

New Yorker, Terrace Room

(J. P. BLEWETT presiding)

Invited Papers in High-Energy Nuclear Physics

F1. Production of Strange Particles in Proton-Proton Collisions. A. M. THORNDIKE, *Brookhaven National Laboratory.* (30 min.)

F2. Elastic Scattering and Single-Pion Production in Proton-Proton Collisions at 2.85 Bev. HORACE TAFT, *Yale University.* (30 min.)

F3. Double Meson Production in Proton-Deuteron Collisions. N. E. BOOTH, *Lawrence Radiation Laboratory, Berkeley.* (30 min.)

F4. Recent Progress in Study of Proton-K-Minus Interactions below 1 Bev/c. J. J. MURRAY, *Lawrence Radiation Laboratory, Berkeley.* (30 min.)

WEDNESDAY AFTERNOON AT 2:00

Statler-Hilton, Terrace Ballroom East

(E. BURSTEIN presiding)

Semiconductors I (Compounds)

FA1. Diffusion of Tin in Gallium Arsenide.* H. P. KELLER AND BERNARD GOLDSTEIN, *RCA Laboratories.*—The diffusion of radioactive tin-113 in GaAs from an evaporated layer has been investigated in the temperature range from 1069°C to 1215°C. The diffusions were carried out in evacuated quartz ampoules which contained an amount of arsenic sufficient to prevent dissociation of the GaAs. Penetration profiles were determined by the use of standard lapping and end-window Geiger counting techniques. These penetration profiles were found to follow the solution to the diffusion equation appropriate to the experimental conditions. The diffusion coefficients of tin can be described by the customary equation $D=D_0\exp(-E/kT)$ where E, the activation energy, is 2.5 ev and D_0 is 6×10^{-4} cm^2/sec. Initial tin concentrations are of the order of 10^{19} atoms/cm^3. The fact that tin acts as a donor in GaAs indicates that it replaces gallium. Since zinc and cadmium act as acceptors, this indicates that they, too, replace gallium. Thus, the fact that the activation energy for tin diffusion is, within experimental error, the same as that reported for the diffusion of cadmium and zinc supports the suggestion of sublattice diffusion in compound semiconductors made in earlier work.

* Sponsored by a contract of the Electronics Research Directorate of the U. S. Air Force Research Division, Air Research and Development Command.

FA2. Free Carrier Absorption in *N*-Type CdS. W. W. PIPER AND D. T. F. MARPLE, *General Electric Research Laboratory.*—Transmissivity and reflectivity of several single crystals of CdS containing difference concentrations of Ga have been measured in the infrared from 2 to 43 μ. In addition to the effect of the lattice vibration, the refractive index and absorption coefficient vary because of the presence of the free carriers. The free carrier contribution to the electric susceptibility can be obtained from the reflectivity on the short wavelength side of the reflectivity minimum and in a few cases directly from the wavelength of the minimum alone. The effective mass for conduction electrons was calculated from the susceptibility and the carrier concentration given by Hall coefficient measurements on the same samples. The effective masses obtained from the optical data are in reasonably good agreement with values previously deduced from mobility measurements[1] and from exciton absorption.[2] The absorption coefficient increases as the 3 to 3.5 power of the wavelength which suggests that the conduction electrons are scattered primarily by charged impurity centers near room temperature. The absolute magnitude of the absorption permits a third estimate of the effective mass.

[1] W. W. Piper and R. E. Halsted, International Conference on Semiconductor Physics (Prague), 1960, V3.
[2] J. J. Hopfield and D. G. Thomas, International Conference on Semiconductor Physics (Prague), 1960, Kl 3.

FA3. Radio-Frequency Zone Melting of CdS, ZnS, ZnSe, and ZnTe. ALBRECHT G. FISCHER, *RCA Laboratories* (introduced by R. E. Shrader).—For the first time, crystals of CdS, ZnS, ZnSe, and ZnTe have been prepared by rf zone melting in graphite boats. Despite the high melting points and corresponding high decomposition pressures, the zone melting was carried out in sealed, standard wall quartz tubing, without enclosing the ampoule in an autoclave or in a block of graphite, as reported earlier.[1,2] The major initial difficulty was the occurrence of explosions. This could be traced to pressure increase due to the cracking of either S_8 or Se_6 molecules in the hot zone to lower species, with a delayed recombination. In the case of the sulfides, a second explosion hazard is caused by the formation of carbon sulfides by direct reaction of sulfur with graphite. These hazards were minimized by increasing the recombination rate of cracked molecules and by increasing the thermal decomposition of the carbon sulfides. Contrary to group III impurities, group IV impurities can be removed by zone refining. *n*- and *p*-type, and insulating crystals, can be prepared.

[1] A. Fischer, Z. Naturforsch. **13a**, 105 (1958).
[2] A. Fischer, J. Electrochem. Soc. **106**, 838 (1959).

FA4. Band Bending and Photoemission in Cs_3Sb.* FREDERICK O. WOOTEN, *Lawrence Radiation Laboratory, Livermore.*—Cs_3Sb is a *p*-type semiconductor and a very efficient photoemitter. There has been speculation that the greater efficiency of *p*-type alkali antimonides arises in part from favorable band bending.[1] Experiments conducted with Cs_3Sb

films show that band bending can be important. The phototube used included a semitransparent Cs_3Sb cathode on a glass envelope. An Al strip provided electrical contact at the Al−Cs_3Sb overlap. At the Al−Cs_3Sb interface, band bending appears to extend for distances of 300 A or greater. If the Cs_3Sb is of thickness less than the range of normal band bending, the charge necessary to establish equilibrium at the Al−Cs_3Sb interface is obtained from regions of Cs_3Sb backed by glass rather than Al. In this way, the influence of band bending can be made to extend for a distance of 1 mm. Photoemission measurements were made in the vicinity of the Al electrode by scanning with a 20-μ-diam light spot. Band bending in the vicinity of the Al electrode was found to enhance photoemission by 25% at 5000 A and by a factor of 2 at 6200 A.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] W. E. Spicer, RCA Review **XIX**, 555 (1958).

FA5. Interband Magneto-Reflection in InSb. GEORGE B. WRIGHT AND BENJAMIN LAX, *Lincoln Laboratory.**—Interband magneto-reflection from InSb has been studied at 80°K in the region from 0.225 to 0.340 ev. Ten lines have been observed in addition to four previously reported from room temperature data.[1] Six lines with inverse effective cyclotron masses of 21, 45, 83, 101, 142, and 158 have been interpreted as heavy-hole electron transitions to the $n=0$, 1, and 2, spin up and spin down, electron bands. The energy gap determined from the zero field intercept of these lines is 0.228 ev. The electron g factor, determined from the splitting of the first two lines, is 48. Unresolved structure in the first two lines, and lines with slopes of 112 and 128, are attributed to "light-hole" electron transitions. The shape of the lines has been matched qualitatively by assuming a complex index of refraction proportional to $1/E_{(\log E)^2}$, which seems to indicate[2] the importance of Coulomb attraction between electron and hole.

* Operated with support from the U. S. Army, Navy, and Air Force.
[1] S. Zwerdling, B. Lax, and L. M. Roth, Phys. Rev. **108**, 1402 (1957); L. M. Roth, B. Lax, and S. Zwerdling, *ibid.* **114**, 100 (1959).
[2] R. J. Elliott and R. Loudon, J. Phys. Chem. Solids **8**, 387 (1959)

FA6. Production of a Low Surface Recombination Velocity on ⟨111⟩ Faces of *n*-Type Indium Antimonide at 77°K. JOHN L. DAVIS, *U. S. Naval Ordnance Laboratory* and *University of Maryland.*—It has been difficult to measure the bulk lifetime of added carriers in n-type InSb[1] because of uncontrollable surface effects. This was confirmed by our initial experiments which indicated a surface recombination velocity s of the order of 10^4 cm/sec, which varied with time and from point to point in the sample. In this work s was measured on the ⟨111⟩ face which is polished by CP-4-A, using the spectral response of the photoconductivity.[2] Low surface recombination velocities were obtained with a two-step process. The first step is etching in CP-4-A, with rinses of demineralized water and absolute methyl alcohol. This gives an s of about 4×10^3 cm/sec at 77°K. Dried nitrogen is then admitted to the vacuum space of the cryostat, where the sample is mounted, until a bright glow discharge can be excited with a Tesla coil. This discharge is applied to the sample for 30 to 60 sec. The resulting surface recombination velocity is approximately 200 cm/sec or less, which is low enough to make surface effects negligible. The uniformity of the surface also is substantially improved.

[1] R. N. Zitter, A. J. Strauss, and A. E. Attard, Phys. Rev. **115**, 266 (1959)
[2] H. B. DeVore, Phys. Rev. **102**, 86 (1956).

FA7. Influence of the Hall Effect upon the Transverse Magnetoresistance in Indium Antimonide. CHARLES A. SIMMONS, *Burrough Corporation Research Center.*—A detailed experimental investigation of the influence of the specimen geometry on the transverse magnetoresistance has been made. Differentiation between the bulk properties and the geometrical contributions has been accomplished. It was found that the enhancement of the magnetoresistance effect in rectangular elements is due to the Hall effect rather than to its absence and that the bulk property has an H^2 relationship while the geometry effect is linear with H and inversely proportional to the length-to-width ratio.

FA8. Band Structure and Transport Properties in *n*-Type PbTe. MONT R. ELLETT, KERMIT F. CUFF, AND CHARLES D. KUGLIN, *Lockheed Missiles and Space Division.*—Resistivity, Hall, magnetoresistance, thermoelectric, Nernst, and magnetothermoelectric measurements have been made in the temperature range from 300°K to 4°K on single crystals of n-type PbTe oriented along the [100] and [110] directions. The magnetoresistance data indicate prolate energy ellipsoids oriented along the ⟨111⟩ axes with an anisotropy ratio K of approximately 4.5 at 300°K, decreasing to 3.3 at 77°K. The energy dependence of the scattering relaxation time ($\tau \propto \epsilon^{\alpha}$) calculated from magnetoresistance, Hall, and thermomagnetic effects are in good agreement. The value of α varies from -0.3 at 300°K to -0.1 at 77°K. The variation of the Hall coefficient with magnetic field (measured at 77 and 4°K) is in qualitative agreement with the measured value of the anisotropy ratio K. The density of states effective mass, calculated from high field Hall data, thermoelectric power, and the energy scattering data, varies from approximately 0.25 at 300°K to 0.15 at 77°K.

FA9. Reactor Irradiation and Annealing of PbTe. J. C. CORELLI, R. T. FROST, AND D. M. AMOROSI, *Knolls Atomic Power Laboratory.**—Samples of n- and p-type PbTe were irradiated in the Engineering Test Reactor at 60±20°C to a total integrated flux-time of 0.50×10^{20} cm^{-2} of neutrons having energies greater than 1 Mev. Room temperature results indicate resistivity increases by factors of 13 and 600 for the n- and p-type samples while the corresponding Seebeck coefficients were increased by factors of 1.8 and 2.3, respectively, as a result of the irradiation. Hall coefficient measurements indicated carrier concentration decreases by factors of 4.7 and ~15 for the n- and p-type samples, respectively. Results for the n-type sample indicate a saturation in the accumulation of damage when compared[1] with results obtained on samples irradiated to lower flux-times. In the isothermal annealing experiments performed on the n-type sample measurements of resistivity, Seebeck and Hall coefficients were made successively. The resistivity and Hall coefficient decayed with similar rates. Recovery rates for this sample were greatest in the temperature range 150–180°C with no unannealable damage in its properties. Similar annealing results for the p-type sample will be given.

* Operated by the General Electric Company for the U. S. Atomic Energy Commission.
[1] J. C. Corelli, R. T. Frost, and F. A. White, Bull. Am. Phys. Soc. Ser. II, **5**, 168 (1960).

FA10. Electrical Properties of Some Cerium Sulfide Semiconductors from 4°K to 1300°K. I. N. GREENBERG, F. M. RYAN, F. L. CARTER,* AND R. MILLER,* *U. S. Army Signal Research and Development Laboratory.*—The electrical properties were measured for a series of sintered cerium sulfide compounds of the thorium phosphide structure. The compounds were in the composition range Ce S_x ($1.33<x\leq1.5$) and were prepared with and without strontium doping. The electrical resistivity was found to increase with temperature in the range 300°K to 1300°K with a temperature dependence that varied from sample to sample. A corresponding increase was observed in the Seebeck coefficient. The addition of strontium doping to compositions for ($x>1.33$) led to a decrease in the resistivity and Seebeck coefficient while maintaining the same temperature dependence. The temperature

dependence may be partially explained by electronic interactions with optical phonons.

* Associated with the Westinghouse Electric Corporation Research Laboratories, Pittsburgh, Pennsylvania.

FA11. Some Optical Properties of Zinc Selenide. D. T. F. MARPLE, M. AVEN, AND B. SEGALL, *General Electric Research Laboratory.*—Zinc selenide single crystals have been prepared by the vapor growth technique. Temperatures of 1350°C and growth rates of about 1 cm per day have yielded boules up to 2 cm in diameter and 3 to 4 cm long. Optical properties of these crystals in the absorption edge region have been studied at room temperature and liquid hydrogen temperature by transmission through polished sections a few microns thick and by reflection of polarized light at 80° angle of incidence from cleaved faces and from chemically polished surfaces. The optical constants of ZnSe have been calculated from these data. At low temperatures two strong narrow absorption peaks appear with the onset of strong absorption at 2.80 ev. A much broader peak appears at about 3.2 ev. The narrow peaks are interpreted as the lowest states of a direct "hydrogenic" exciton series with a reduced mass of about $0.1m_e$. The broad maximum may be caused by excitons formed with hole states of the split-off valence band. Infrared reflectance at room temperature has been measured in the 25- to 42-μ wavelength range. Analyzed with a classical single-oscillator model, these data give the energy of the transverse optical phonon as about 0.027 ev.

Invited Paper

FA12. Free-Carrier Voigt Effect in Semiconductors. S. TEITLER, *U. S. Naval Research Laboratory.* (30 min.)

WEDNESDAY AFTERNOON AT 2:00

New Yorker, Panel Room

(E. L. HAHN presiding)

Mostly Magnetic Resonance

G1. Rotational Magnetic Moments of HF, DF, and CH_4.* M. R. BAKER, C. H. ANDERSON, J. PINKERTON, AND NORMAN F. RAMSEY, *Harvard University.*—The rf spectra corresponding to reorientations of the molecular rotational magnetic moments have been studied in the molecules HF, DF, and CH_4 by means of the molecular beam resonance method. A recently constructed beam apparatus with an electron bombardment detector was used for the experiments, which were carried out in fields of 5700 and 7500 gauss. From an analysis of the observed spectra, the effective rotational magnetic moments of HF and DF were found to be $+0.7392\pm0.0005$ nm and $+0.3695\pm0.005$ nm, respectively. The magnitude of the rotational moment of CH_4 was 0.3133 ± 0.0005 nm. From the ratio of the rotational magnetic moments of HF and DF, the electric dipole moment for the HF molecule can be determined to be 1.69 ± 0.05 debyes.

* Work supported by the National Science Foundation and by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

G2. Double Resonance Studies of Asphaltene Solutions. EDWARD H. POINDEXTER, *California Research Corporation.*—A dipolar Overhauser interaction occurs between asphaltene free radicals and the protons of surrounding solvent molecules. The enhancement of the proton resonance signal may be characterized by four parameters: T_{1e}, T_{2e}, and a line-width constant T_{2e}^* for the electron; and a factor f_r related to the fraction of proton relaxation arising from interaction with the electron. The quantity $(\gamma_e^2 T_{1e} T_{2e})^{-\frac{1}{2}}$ varies from 0.5 gauss in dilute solutions of asphalt in xylene to 0.1 gauss in concentrated. The factor f_r increases with concentration until the solute's influence dominates the proton relaxation. At low asphalt concentrations, the rf power dependence of the proton signal enhancement appears like that arising from a homogeneously broadened electron resonance. A slight amount of inhomogeneity appears when $(\gamma_e^2 T_{1e} T_{2e})^{-\frac{1}{2}}$ starts to decline in higher concentrations. The observed power dependence is best fitted by the values: $T_{1e}=3.4\times10^{-7}$ sec, $T_{2e}=3.0\times10^{-8}$ sec at low concentrations; $T_{1e}=2.4\times10^{-6}$ sec, $T_{2e}=5.3\times10^{-8}$ sec at high. The magnitude of the proton signal enhancement as a function of asphalt concentration can be explained reasonably well, but the behavior of the electron saturation parameters is not well understood at present.

G3. Nuclear Magnetic Resonance of Neutron-Irradiated LiF.* CHARLES D. KNUTSON AND P. J. BRAY, *Brown University.*—Molecular fluorine and colloidal lithium metal present in crystals produce distinctive nuclear magnetic resonance absorptions.[1] The identifications of these absorptions are well established both by nuclear magnetic resonance properties and other experiments. Lithium fluoride single crystals and powders which have received pile-neutron irradiation from 10^{18} to 10^{20} nvt have been examined. The molecular fluorine absorption intensity increases proportionally to neutron flux up to about 10^{19} nvt. Above this flux region the absorption remains constant at a value of about 1% of all fluorine atoms. Colloidal lithium absorptions are not usually observed in unannealed samples. The absence of colloid absorption in unannealed samples and the presence of the absorption in annealed samples reflects the growth of Li colloids during annealing. Powder samples do not show molecular fluorine absorptions as crystals do. This result supports the theory of irreversible metal fromation due to loss of fluorine. These observations are contrasted with electron spin results under the same irradiation conditions.

* Research supported by the U. S. Atomic Energy Commission and the National Science Foundation.

[1] P. J. Ring, J. G. O'Keefe, and P. J. Bray, Phys. Rev. Letters 1, 1508 (1958); *ibid.* 2, 64 (1959).

G4. NMR Investigation of the Structure of Lead Borate Glasses.* M. LEVENTHAL AND P. J. BRAY, *Brown University.*—The B^{11} resonance has been studied in lead borate glasses as a function of composition. It is found, as expected, upon the basis of previous NMR work[1] with alkali borate glasses, that the boron goes from 3- to 4-coordination as the percentage of lead oxide increases. This trend is clearly observable as the 3-coordinated boron has a large quadrupole interaction while

the 4-coordinated does not. Contrary to previous proposals, the fraction of boron which is 4-coordinated is seen to increase until well over 50 molar percent of lead oxide has been added. One then observes a decrease in the amount of 4-coordinated boron as the lead oxide content is increased. This is in agreement with a prediction by R. W. Douglas[2] based upon the infrared data obtained by Sen. A study of the Pb^{207} resonance in the same glasses is in progress. A report will be made on this investigation.

* Research supported by the Owens-Illinois Glass Company and the Office of Naval Research.
[1] A. H. Silver and P. J. Bray, J. Chem. Phys. **29**, 984 (1958).
[2] R. V. Adams and R. W. Douglas, 5th Internationaler Glass Kongress 32 K (Munich, Germany, 1959), Heft VII, VII/12–VII/24.

G5. Paramagnetic Relaxation of the Cr^3 Ion in Cesium Chrome Alum.* P. B. KISSINGER AND R. T. WEIDNER, *Rutgers University*.—The steady-state saturation method was used to investigate the paramagnetic relaxation of the chromium ion in cesium chromium (aluminum) sulfate at 24 kMc and at liquid helium temperatures. The relaxation behavior was studied as a function of the intensity of the microwave field, the magnetic transition, the magnetic ion concentration, and the temperature. For the power range used, a single relaxation parameter was found adequate to describe the saturation behavior. The Cr/Al ion concentration was varied between 1/0 and 1/93. For each of the magnetic transitions investigated, it was found that the relaxation parameter increased with magnetic dilution. For all of the samples tested, the temperature dependence of the relaxation parameter τ in the range 1.6°K to 4.2°K could be expressed by the relation τT^n=constant with $n=-1$. The results suggest that, for these samples, the direct process interaction is the dominant energy bottleneck and that more energy transfer paths are available at the higher magnetic concentrations.

* Supported in part by the Office of Naval Research.

G6. Structured Cyclotron Resonance in Gases.* H. G. ROBINSON, *Yale University*.—Structure in the electron cyclotron resonance in various gases has been observed previously.[1,2] This effect can be explained on the basis of the known energy-dependent collision cross section σ. The power absorbed by the electrons is proportional to the number of collisions per second between the electrons and the gas. Thus the intensity of the resonance is proportional to the product $v\sigma$, where v is the electron velocity. Consider electrons heated by the applied rf field whose frequency ω is near the resonance frequency ω_0. For $\omega \lesssim \omega_0$, the electron velocity is less than that for $\omega=\omega_0$. If there is a sufficiently rapid decrease of σ with energy, it is possible to have $(v\sigma)|_{\omega} > (v\sigma)|_{\omega_0}$. Thus a doublet would be observed. Where a Lorentzian line shape is expected, the separation between peaks will increase with the square root of the rf power. More complex line shapes can be obtained if the electron energy is greater than that corresponding to the first minimum of the collision cross section.

* This work was supported in part by the National Aeronautics and Space Administration.
[1] R. L. Collins, Bull. Am. Phys. Soc. Ser. II, **5**, 343 (1960).
[2] R. Kohin and R. S. Anderson (private communication).

G7. Paramagnetic Resonance of Iron in Beryl.* N. L. MILDER AND L. C. BROWN, *The Ohio State University*.—Dvir and Low[1] recently have published data on the EPR spectra of Fe^{+++} in a single beryl crystal for certain crystal orientations. We also have investigated these spectra at room temperature in a similar beryl crystal as a function of crystal orientation. The spectra obtained for the aluminum sites are in substantial agreement with the earlier work. The variations in line positions can be interpreted in terms of two equivalent but differently oriented aluminum sites occupied by Fe^{+++}. A plot of the variation in line position with crystal orientation will be displayed. The question of assignments and the determination of physical constants will be discussed. No attempt was made to analyze the variation of the many weaker lines observed.

* Supported in part by the U. S. Air Force Office of Scientific Research.
[1] M. Dvir and W. Low, Phys. Rev. 119, 1587 (1960).

G8. Compensation Dependent Electron Spin Relaxation in *n*-Type Silicon.* G. YANG AND A. HONIG, *Syracuse University*.—Spin-lattice relaxation of phosphorus donor electrons in a compensated silicon sample containing $6\times10^{15}/cm^3$ phosphorus impurities and $2\times10^{15}/cm^3$ boron impurities has been investigated at liquid helium temperatures. By subtracting from the measured relaxation probability the relaxation probabilities due to mechanisms found in uncompensated samples,[1] one obtains the relaxation probability due to compensation. The temperature and magnetic field dependences for this compensation dependent mechanism have been determined. In addition, the dependence of this relaxation probability on concentration of *charged* impurities has been obtained by employing a recently developed technique.[2] This technique permits control of the concentration of ionized impurities in compensated samples by supplying charged impurities with photoexcited electrons and holes from the valence band. The results of these experiments are consistent with a previously suggested interpretation[1] that relaxation results from spin diffusion from relaxation centers consisting of phosphorus ion-phosphorus neutral pairs, i.e., the analog of the hydrogen molecular ion.

* Supported in part by the U. S. Air Force Office of Scientific Research.
[1] A. Honig and E. Stupp, Phys. Rev. 117, 69 (1960).
[2] A. Honig and R. Levitt, Phys. Rev. Letters **5**, 93 (1960).

G9. Electron Spin Resonance of Irradiated Single Crystals of Urea Compounds.* T. S. JASEJA AND ROY S. ANDERSON, *University of Maryland* and *Clark University*.—Single crystals of urea compounds were x- and γ-irradiated. Electron spin resonance examination at room temperature of urea and thiourea give no evidence of radiation damage under the conditions of the experiment. However, both methylurea and ethylurea had strong electron resonance spectra at $g=2$. Interpretation of these spectra suggested that the radicals formed were $\cdot CH_2NH(CONH_2)$ and $CH_3\dot{C}HNH(CONH_2)$. The spectra observed in methylurea were explained on the basis of the theory developed by McConnell *et al.*[1] The spectra of ethylurea appeared quite similar to those observed in alanine by Miyagawa and Gordy[2] except that the urea lines were somewhat broader. The increase in width was attributed to the closer proximity of the NH group to the unpaired electron. Orientations of the radicals within the unit cell have been proposed.

* Supported by the National Security Agency.
[1] McConnell, Heller, Cole, and Fessenden, J. Am. Chem. Soc. **82**, 766 (1960).
[2] I. Miyagawa and W. Gordy, J. Chem. Phys. **32**, 255 (1960).

G10. Electric Dipole Moment of OH Radical.* G. EHRENSTEIN, *Columbia University*.—The two Λ-doubling transitions for the $J=\frac{1}{2}$ rotational state of the $^2\pi_{\frac{1}{2}}$ electronic state of OH radical have been observed using a microwave spectrometer with sine wave Stark modulation. The absorption cell used in the experiment was glass-lined in order to protect the radicals from the metal walls of the waveguide and the Stark septum. The spectrum which was obtained showed unresolved Stark components. A preliminary value of dipole moment obtained from this spectrum is 2.1 ± 0.4 debyes.

* Work supported jointly by the U. S. Army Signal Corps, the Office of Naval Research, and the U. S. Air Force Office of Scientific Research.

WEDNESDAY AFTERNOON AT 2:00

Statler-Hilton, Terrace Ballroom West

(A. C. KOLB presiding)

Plasma Physics

GA1. Magnetohydrodynamic Results for Highly Dissociated and Ionized Air Plasma Produced by Hypersonic Shock Waves.* H. T. NAGAMATSU AND R. E. SHEER, JR., *General Electric Research Laboratory.*—An investigation of air plasma moving through a constant (2300-gauss) transverse magnetic field was conducted in a shock tube. As the plasma traveled through the field, an electromotive force was produced in the plasma. Two diametrically opposite, ¼-in. diam, copper electrodes were used to measure this potential. The shock Mach number varied from 10 to 32 with corresponding equilibrium plasma temperatures from 3600 to 11 000°K. At Mach 30 the observed potential across the electrodes, with a 1-meg external load, was 236 v, which agreed with the theoretical value, but at lower Mach numbers the observed potentials were much lower than theory. By varying the external load for a shock Mach number of 30, the current from the plasma varied from nearly zero to 115 amp. This high current was extracted from the copper electrodes at nearly room temperature. The observed potential decreased linearly with increasing current indicating a nearly constant plasma resistance. For this resistance the electrical conductivity was calculated and was much less than the theoretical prediction. The maximum power extracted from the plasma was 7.8 kw with an external load of 1.85 ohms.

* This research has been partially supported by the U. S. Air Force.

GA2. Plasma Containment in a Cusp Geometry. LEWIS S. COMBES, CHARLES C. GALLAGHER, AND MORTON A. LEVINE, *Air Force Cambridge Research Laboratories.*—A cusp type geometry entitled "Romac" has been designed and tested in which the characteristics of the cusp field are maintained except that there is no stagnation point or magnetic field zero. This geometry may best be described as a four-pole cusp field mixed orthogonally with a mirror field. The two fields may be applied independently. A report of the behavior of this device in terms of field trapping by the plasma will be presented.

GA3. Plasma Formation at Low Pressure. MORTON A. LEVINE, *Air Force Cambridge Research Laboratories,* AND ALLEN G. RUBIN, *Williamson Development Corporation.*—A method has been developed for producing plasmas at low pressures by means of an electrodeless discharge. A high-power pulsed rf voltage is applied to a single-turn coil surrounding a toroidal discharge vessel. Plasmas have been produced at pressures down to 8×10^{-7} mm Hg in various gases. A theory of formation of the discharge will be presented. In this theory secondary electron production by means of wall bombardment supplies the collision mechanism.[1] Experimental studies of the discharge properties will be reported.

[1] E. W. B. Gill and A. von Engel, Proc. Roy. Soc. (London) A192, 446 (1948).

GA4. Equilibrium Solutions of Infinitely Long *E*-Layer in Astron.* C. C. CHANG† AND T. S. LUNDGREN,† *Lawrence Radiation Laboratory, Livermore.*—Investigation is made for the equilibrium case of an infinitely long Astron[1] *E* layer and for a simplified model consisting of a plane sheet of streaming electrons. Equilibrium solutions are obtained with the continuum concept of three fluids, one of relativistic electrons, the second of plasma electrons, and the third of plasma ions (which include the ions which neutralize the beam). For the case of a plane sheet of relativistic electrons, the distribution of the self-induced magnetic and electric fields (so-called self-consistent fields) are studied. If the temperature distributions of plasma electrons and ions are not uniform, but are similar to the distribution of number density of the beam, some solutions for the beam number density also are obtained. For the case of an applied uniform axial magnetic field, the beam is bent into a rotating cylindrical sheet as the Astron *E*-layer. The centrifugal term can be evaluated as a perturbation of the plane sheet beam.

* This work was done under the Auspices of the U. S. Atomic Energy Commission.

† Consultants to the Lawrence Radiation Laboratory, Livermore, California, from the University of Minnesota, Institute of Technology.

[1] N. Christofilos, "Astron thermonuclear reactor," Lawrence Radiation Laboratory Rept., UCRL-5032.

GA5. Heat Shield Response of an Irradiated Plasma.* J. I. F. KING, M. M. KLEIN, AND E. L. GRAY, *General Electric Space Sciences Laboratory.*—For certain ranges of plasma parameters it is possible to couple rf power instantaneously to a plasma with the resultant beam attenuation appearing as ohmic heating of the medium. If the irradiated plasma is thermally ionized, the medium will react to this additional heat source with an increase in local electron density roughly coincident with the heat input pattern. The new electron density distribution will in turn give rise to a new heating pattern. The heat-flow equation is solved incrementally for a plane-parallel inhomogeneous plasma whose electron density increases exponentially in the direction of propagation of the incident rf beam. Calculations showing the dynamic response of the plasma to the radiation will be presented. As expected on qualitative argument, the heating zone rapidly moves upstream, exhibiting the self-shielding effect of the plasma. At the same time the beam reflection increases greatly as the electron density gradient is sharpened. The Saha equation is used to couple the electron density to the temperature field.

* Supported by Rome Air Development Center contract.

GA6. Use of Probes in Oscillatory Plasmas.* FRANCIS F. CHEN, *Princeton University.*—Many plasmas of interest in the field of highly ionized gases are unstable against electrostatic oscillations and exhibit fluctuations in local potential of the order of kT_e. Under such conditions determinations of kT_e by classical Langmuir probes are suspect, since probe current fluctuates nonlinearly with potential. The method of floating double probes does not solve the problem, since it samples only the fastest electrons. In an alternative method, we have used two probes, one floating and one biased, separated by a distance much less than the correlation length of the oscillations. The instantaneous probe potential and probe current are then displayed on the axes of an oscilloscope. Comparison with classical probe measurements in a reflex discharge showed no serious distortion of the measured electron temperature by the oscillations.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

GA7. Calculation by the WKB Method of the Interaction of a Nonuniform Plasma with Microwave Radiation.* M. M. KLEIN AND J. I. F. KING, *General Electric Company.*—The interaction of an infinite nonuniform plasma with a plane electromagnetic wave has been obtained by the WKB method

for several values of the electron density gradient and collision frequency. The calculated values of reflection coefficient and rate of absorption within the plasma are compared with those obtained by numerical solution.[1] The values of the reflection coefficient by the WKB method are in good agreement with the more exact values at short wavelengths, the agreement becoming poorer as the wavelength increases. The rate of absorption by the WKB method shows, as anticipated, only fair agreement with the more exact calculation, the agreement becoming poorer as the plasma frequency approaches the frequency of the incident radiation.

* Based on work peformed under the auspices of the U. S. Air Force.

[1] Klein, King, Greyber, and Brueckner, "Interaction of a nonuniform plasma with microwave radiation," *Proceedings of Plasma Sheath Symposium* (Pergamon Press, New York, 1960).

Post-Deadline Papers, if Any

WEDNESDAY AFTERNOON AT 2:00

New Yorker, Boston-Washington Room

(W. W. TYLER presiding)

Crystals

H1. An LCAO Theory of the $k=0, 0, 0$ Valence Band Splittings in Zinc Blende and Wurtzite Structures. S. ADLER* AND J. L. BIRMAN, *General Telephone and Electronics Laboratories.*—Bloch sums of localized functions having the transformation properties of angular momentum eigenfunctions with $J^2=\frac{3}{2}$ and $\frac{1}{2}$ (s and p orbital parts) are used to set up the Hamiltonian matrices at $k=0, 0, 0$ for zinc blende and wurtzite structures. By means of perturbation theory, accurate expressions are obtained for the valence band eigen energy splittings in each structure, in terms of appropriate crystal potential matrix elements. A series of approximations, probably valid for ZnS in both crystal structures, now can be made: First order; first neighbor; two center; neglect of Zn $4p-S3p$ mixings; band gaps greater than any valence band splittings and greater than the matrix elements of the difference between zinc blende and wurtzite potentials. All valence band splittings (one in zinc blende and two in wurtzite) then can be expressed in terms of two parameters:[1] δ (spin orbit) and α (uniaxial field), which can be estimated theoretically from an assumed crystal potential. Experimentally, for ZnS one finds from reflection measurements, made on pure zinc blende and wurtzite crystals, $\delta=0.068$ ev and $\alpha=-0.023$ ev at 77°K. The theory may be applied to CdS (zinc blende structure) and predicts a valence band splitting of 0.065 ev at 77°K in this material.

* Now at Physics Department, Harvard University.

[1] J. J. Hopfield (to be published); J. L. Birman, Phys. Rev. 114, 1490 (1959).

H2. Limiting Optical Frequencies in Ionic Crystals. A. A. MARADUDIN, *Westinghouse Research Laboratories,* AND G. H. WEISS, *University of Maryland.*—It recently has been pointed out by Rosenstock on the basis of symmetry arguments that the frequencies of the three optical branches of an ionic crystal in the limit of infinite wavelengths are all equal. This result is in contrast with the relation $(\omega_l/\omega_t)=(\epsilon_0/\epsilon_\infty)^{\frac{1}{2}}$ due to Lyddane, Sachs, and Teller, where ω_l and ω_t are the limiting longitudinal and transverse frequencies and ϵ_0 and ϵ_∞ are the static and high-frequency dielectric constants, respectively. By use of Kellerman's model for NaCl we have obtained the small k expansions of the elements of the dynamical matrix for a finite spherical crystal of radius R. It is found that, if the limit $k\to 0$ is taken before the limit $R\to\infty$, the three optical frequencies are all equal, while if the order of taking limits is reversed the result of Lyddane, Sachs, and Teller is obtained. These conclusions are in agreement with Rosenstock's result, and with remarks of Frohlich, and provide an explicit expression for the infrared frequency in the finite crystal case. A similar calculation for Wigner's low-density electron crystal yields the result that in a finite spherical crystal the limiting frequencies of the two transverse branches and the one "longitudinal" branch are all equal.

H3. Entropies, Heats of Sublimation, and Dissociation Energies of the Cesium Halides. JOSEPH FINE AND MILTON D. SCHEER, *National Bureau of Standards.*—The vapor pressures of the crystalline cesium halides have been measured in the 700–900°K temperature range. The salt vapor effusing from a Knudsen effusion cell was collimated accurately into a molecular beam with a well-defined cross-sectional area. Beam intensities were determined from the positive ion currents produced by dissociation of the halide and ionization to Cs^+ on a tungsten surface at 1700°K. From the experimental vapor pressures and heats of sublimation, the crystal entropies, dissociation energies, and heats of sublimation at 298°K were computed using available spectroscopic and thermal data.

H4. Diffusion Theory Approach to Electrical Breakdown in Alkali Halides. E. OFFENBACHER AND S. W. SPAULDING, *Temple University.*—The problem of electrical breakdown in alkali-halide crystals has been studied using a diffusion equation. The conduction electrons are assumed to diffuse in energy space under the influence of phonon collisions and the applied field. The average first transit time required for an electron to gain a significant energy is calculated as a function of applied field. The significant energy for any given field is taken to be that above which the electrons on the average gain energy more rapidly than they lose energy to the lattice. The average first transit time is a parameter which can be compared to the recombination time of electrons excited to the conduction band by impact ionization. When the transit time becomes less than the recombination time, the number of electrons excited to the conduction band increases rapidly, and electrical breakdown is said to occur. Approximate knowledge of such recombination times permits one to define approximately the breakdown field strength.

H5. Ultraviolet Absorption of the Mixed System KCl-KBr.* HERBERT MAHR, *Cornell University* (introduced by P. L. Hartman).—The ultraviolet absorption of thin evaporated layers and the edge absorption of single crystals of the mixed system KCl-KBr were measured at room temperature in the photon energy range from 6 to 11 ev. In the thin layers both the Cl^- and the Br^- absorption bands are present in the

mixtures, and their sizes depend on the relative concentration of the two ions. The energy values of the bands generally shift with composition, although in contrast to all the other bands the high-energy KBr band shifts very little. A simple semi-classical electron transfer model can describe the results obtained for the lower energy bands. Possible explanations for the deviation in behavior of the high-energy bands will be discussed.

* Work supported by the Office of Naval Research and the Advanced Research Projects Agency.

H6. Scattering of Helium and Argon from the Cleavage Plane of Lithium Fluoride. JAMES C. CREWS, *Union Carbide Nuclear Company.*—The scattering of helium and argon from the cleavage plane of lithium fluoride has been studied using molecular beam techniques and under vacuum conditions which were somewhat better than are typical for systems of this type. The helium measurements confirm the diffraction effects reported by O. Stern and co-workers and reveal, in addition, a broad scattered beam which appears to be symmetrical about the specular position. Measurements with argon beams gave a scattering pattern which was quite different from that obtained for helium. The scattered beam was very broad and had an intensity maximum between the specular position and the crystal normal. Analysis of the data showed that this deviation of the maximum from the specular position cannot be obtained by superposition of specular and cosine law scattering components. Furthermore, the dependence of argon scattering on angle seems to be inconsistent with a diffraction mechanism.

* This document is based on work performed at the Oak Ridge Gaseous Diffusion Plant operated by Union Carbide Corporation for the U. S. Atomic Energy Commission.

H7. Study of Birefringence Resulting from Dislocations in Slip Planes in Alkali-Halide Single Crystals. SOL MENDELSON, *Columbia University.*—A birefringence technique was developed to emphasize the difference in stress on each side of a slip plane having an array of equally spaced equal sign edge dislocations. This permits a determination of the sign of the dislocations in the slip plane and also the apparent position of its source. Each side of the slip plane (which is oppositely stressed) acts as a double refracting medium and produces opposite retardations in phase. In the conventional birefringence method the background intensity (unstressed region) is set for extinction, and both retardations produce an increase in intensity. The resulting band does not reveal the difference in stress on each side of the slip plane. This difference can be emphasized by retarding the light leaving the crystal by an amount equal to the advancement from the compressive region (or to advance the light by an amount equal to the retardation from the tensive region). The resulting birefringence band is, for instance, dark on the compressive side, light on the tensive side, in a background having an intensity halfway between these two shades. Examples of birefringence bands in ionic crystals and their correlation with dislocation etch pits are given.

H8. Effects of Oxygen Vacancies on the Dielectric Properties of Rutile (TiO_2). PATRICIA L. CASTRO AND LEWIS E. HOLLANDER, JR., *Lockheed Missiles and Space Division.*—Measurements have been made of some of the properties of nonstoichiometric single crystals of rutile TiO_2 in which the oxygen content varied over a range corresponding to specific resistivity from 10^4 to 10^{13} ohm cm. The dielectric constant and the loss tangent were determined for both the "*a*" and "*c*" crystallographic directions for frequencies between 60 cps and 300 kc. Measurements of capacitance made with crystals which were systematically decreased in thickness showed a linear dependence of capacitance with inverse thickness. No rectification was observed with asymmetrical electrodes. These results indicate a strictly bulk dielectric effect. A direct correlation between dielectric constant and oxygen vacancy density is shown. The nonstoichiometric compositions exhibit an increase in dielectric constant and dielectric loss at low frequencies. Loss measurements in the "*c*" direction have a minimum at 200–300 cps and a peak at 10^4 cps; these maximums and minimums are not observed in the "*a*" direction. The results of this study suggest that the dielectric behavior of rutile may be explained on the basis of an artificial dielectric theory which considers regions of conductors embedded in an insulating matrix.

H9. Dislocation Decoration Inside Silver Chloride Crystals.* LAWRENCE SLIFKIN, *University of North Carolina,* AND CHARLES B. CHILDS, *Goddard Space Flight Center.*—A method for the decoration of dislocations throughout the *interior* of large single crystals of silver chloride which does not require an annealing treatment at elevated temperatures has been developed. The crystals are moderately loaded with submicroscopic colloidal silver by means of the Haynes-Shockley photoelectric technique. They are then allowed to age for several days at room temperature, during which time much of the silver migrates from random scattering centers into the dislocations. This results in such an increase in the constrast between the decorated dislocations and the background that the dislocation structures then can be examined with ordinary bright-field microscopy and to depths of the order of millimeters. Photographs of various networks and dislocation structures obtained by this technique will be shown. Since no high-temperature annealing is necessary, this method suggests the possibility of studies of plasticity effects in the cold-worked state, without the limitation of surface effects.

* Supported in part by the Office of Scientific Research, U. S. Air Force.

H10. Diffusion Paths and Activation Energies in AgI and ZnO Crystals.* LEONID V. AZÁROFF,† *Illinois Institute of Technology.*—The diffusion paths in hexagonal closest packed structures consist of successive octahedral voids and in cubic closest packed structures of alternating octahedral and tetrahedral voids. The saddle points encountered in both paths are the same since two adjacent voids share a triangular face composed for three closest packed atoms. The activation energy for diffusion is primarily composed of the saddle-point energies because other terms tend to cancel. The existence of continuous paths in the zinc blende and wurtzite structures eliminates the need for vacancies, and it can be shown that the activation energy in β AgI is twice that in γ AgI because two saddle points must be crossed in the wurtzite structure as opposed to one only in zinc blende. Similarly, it can be shown that the different activation energies for diffusion of Zn in ZnO measured by electrical and by tracer methods can be explained when actual diffusion paths are considered.

* Research supported by Office of Scientific Research, U. S. Air Force.
† Work performed while guest at Brookhaven National Laboratory.

H11. Mondrian Precipitation Patterns in Single Crystals of Titanium Carbide. WENDELL S. WILLIAMS, *National Carbon Company.*—Electrolytic etching studies have been carried out on large single crystals of titanium carbide—a refractory hard metal with the NaCl crystal structure. Square, *flat-bottomed* pits with edges in ⟨100⟩ directions were produced on the {100} cleavage planes. By x-ray and metallographic examination these pits were shown to be related to precipitates of excess carbon and not to dislocations. The observations are thus similar to those of Gilman[1] on LiF. Annealing these crystals in a vacuum of 10^{-6} mm Hg at 2000°C for 1 hr redistributed most of the excess carbon into the form of platelets lying along {111}

planes. Etched cleavage surfaces showed dark linear traces marking the intersections of these {111} lamellar precipitates with the {100} cleavage planes. The patterns observed microscopically are reminiscent of abstractions painted by the Dutch artist, Piet Mondrian.

[1] J. J. Gilman, J. Appl. Phys. **30**, 1584 (1959).

H12. Oriented Polygonal Voids in Single Crystal Tin Films. RICHARD W. VOOK, *IBM Research Laboratory, Poughkeepsie.*—In the course of an investigation of the properties of evaporated single-crystal tin films, we have obtained several films containing polygonal voids whose sides are oriented along crystallographic directions. Voids in the thicker films (around 2000 A) are often rectangular. One film 1000 A thick had many octagonal voids in it. Tin has a tetragonal lattice. The films are oriented with the "*C*" axis normal to the plane of the film. The sides of the voids tend to lie along the closest packed planes of the lattice, that is, the (100) and (110) planes. Single-crystal films are produced by evaporating tin on NaCl substrates at liquid nitrogen temperature in ultra-high vacuum and then warming the resulting film to room temperature. They are then removed from the substrates and mounted on grids for electron optical examination. It is believed that the oriented voids arise from the condensation of migrating vacancies or divacancies on the closest packed planes adjacent to voids already present in the film. This process probably occurs at some temperature during warmup where vacancies or divacancies anneal out.

H13. Sapphire Whisker Growth on a Single-Crystal Substrate. P. L. EDWARDS* AND R. J. HAPPEL, JR., *U. S. Naval Ordnance Laboratory.*—Sapphire whiskers have been grown on exposed planes of single crystals of sapphire by heating aluminum filings, located near the crystals, to 1400°C in a stream of wet hydrogen.[1] The whiskers grew only in certain directions with respect to structure of the base crystal. Polarized-light examination showed them to be crystallographically coherent with the substrates. The axes of the whiskers were either parallel to the *c* axis or to one of twelve equally spaced directions in the basal plane. These twelve directions divide into two distinct sets, a $2\bar{1}\bar{1}0$ set and $10\bar{1}0$ set, with each having sixfold symmetry about the *c* axis, and with the members of one set midway between members of the other. These and the *c* direction are the Burgers vectors' directions in sapphire; hence it seems plausible that the whiskers grow coherently with the substrate at the sites of emergent screw dislocations.[2] This is in agreement with the work of Webb and Forgeng[1] who have found axial screw dislocations in sapphire whiskers with axes in the *c* direction.

* Now at Texas Christian University, Fort Worth, Texas.
[1] W. W. Webb and W. D. Forgeng, J. Appl. Phys. **28**, 1449 (1957).
[2] Peter Gibbs, *Kinetics of Temperature Processes* (John Wiley & Sons, New York, 1959).

WEDNESDAY AFTERNOON AT 4:45

New Yorker, Terrace Room

Business Meeting of The American Physical Society

THURSDAY MORNING AT 10:00

STATLER-HILTON, Terrace Lounge

(L. J. LIDOFSKY presiding)

Nuclear Reactions I

I1. Density of States in Be^{8}.* EVERET H. BECKNER AND G. C. PHILLIPS, *Rice University.*—The generalized density of states function of Phillips, Griffy, and Biedenharn has been used to deduce the cross section for particle emission which exists for several reactions leading to Be^{8*}. This cross section was calculated assuming that the reaction $a+A \rightarrow D^* \rightarrow b+C+c$ occurred as a sequence of the two-body decays: $D^* \rightarrow B^*+b$ and then $B^* \rightarrow c+C$. Knowledge of the phase shift for the two-body channel $c+C$ permits the cross section for emission of particles b to be calculated from the density function $\rho(E_B)=\pi^{-1}d/dE_B[\delta_l(E_B)+\phi_l(a,E_B)]$. The reactions studied were $B^{11}(p,\alpha)Be^{8*}$ and $Be^{9}(p,d)Be^{8*}$, with a 180° magnetic spectrometer employed as detector. In both of these reactions there are two ways of emitting particles of type b. In the case of B^{11}: $B^{11}+p \rightarrow C^{12*} \rightarrow Be^{8*}+\alpha \rightarrow \alpha+\alpha+\alpha$. In the case of Be^{9}: $Be^{9}+p \rightarrow B^{10*} \rightarrow Be^{8*}+d$ or $B^{10*} \rightarrow Li^{6*}+\alpha \rightarrow d+\alpha+\alpha$. Consequently it was necessary to include these contributions in comparing the results of the theory with the experimentally observed spectra. It has been possible to fit the spectra without including any contributions resulting from the simultaneous emission of the three particles. The experiments give evidence for a spectral anomaly due to the localized production of Be^{8} and confirm the two-step nature of the the reactions.

* Supported by the U. S. Atomic Energy Commission.

I2. Radiative Capture of Protons in Be^{9}.* C. A. LUDEMANN, M. L. ROUSH,† AND WILLIAM F. HORNYAK, *University of Maryland.*—Two γ-ray coincidence techniques have been utilized in the investigation of the γ-ray branching in the decay of the two presumably $T=1$ levels at 7.48- and 7.56-Mev excitation in B^{10} using the $Be^{9}(p,\gamma)$ reaction. Originally this investigation was aimed at determining the mixture of $T=0$ and $T=1$ character of these levels (such admixtures were believed evident since, for example, α and d decay as well as $E1$ radiation is present from the broad level at 7.48 Mev). The experiment, however, unambiguously reveals multiple structure for the broad level in agreement with recent work.[1,2] The levels in question have widths 50–100 kev, the lowest of which decays primarily to the 1^+ first excited state at 0.72 Mev. The possible spin and parity assignments of these levels will be discussed.

* Supported in part by the U. S. Atomic Energy Commission.
† Now at Baker University.
[1] J. Kantelle, Ann. Acad. Sci. Fennicae Ser. VI, No. 37 (1959).
[2] L. Simons, Soc. Sci. Fennica, Commentationes Phys.-Math. **XXIV**, 8 (1960).

I3. Polarization of Protons in $Be^{9}(d,p)Be^{10}$.* R. G. ALLAS AND F. B. SHULL, *Washington University.*—The polarization of protons from the ground-state $Be^{9}(d,p)Be^{10}$ stripping reaction has been measured for an incident deuteron energy

$E_d=10$ Mev by a technique previously reported.[1] The axis of quantization is defined according to the Basel convention as $\mathbf{n}=\mathbf{k}_d\times\mathbf{k}_p$. With this definition the sign of polarization agrees with the rule $P(\pm)$ as $j_n=l_n\pm\frac{1}{2}$. The measured polarizations were (18.5±3.8)% at 15.5° (lab); (0.1±2.7)% at 19.5°; (6.3±3.2)% at 24.5°; (10.4±3.0)% at 29°; (8.3±6.4)% at 32.5°; (17.3±5.6)% at 37.8°; (28.5±9.7)% at 42.5°; (18.2±7.4)% at 46°; (33.4±12.7)% at 52°; (33.0 ±13.7)% at 56°. Additional data will be presented.

* Supported by the U. S. Air Force Office of Scientific Research of the Air Research and Development Command.
[1] R. G. Allas and F. B. Shull, Phys. Rev. 116, 996 (1959).

I4. (Abstract withdrawn.)

I5. Energy Dependence of the Differential Cross Section for $C^{13}(p,p)C^{13}$.* W. Daehnick, M. Garrell, R. Wood, and R. Sherr, *Princeton University.*—Differential cross sections for scattering angles of 70° to 160° (in intervals of 10°) have been obtained as a continuous function of the bombarding energy over a range from 14 to 19 Mev. Use was made of the fact that in a thick target the scattering energy of the protons varies over a range ΔE determined by the target thickness. If the scattered particles are observed at back angles, they show an energy spread of $>2\Delta E$, and their pulse height spectrum is simply related to $\sigma(E,\theta)$. Thus for C^{13}, with the first excited state 4.4 Mev removed from the ground state, a continuous excitation function for an energy interval of about 1.6 Mev could be obtained in one run. The energy resolution was about 250 kev because of the limited resolution of the NaI crystal and the spread in the cyclotron energy. As was suspected from earlier data obtained by Peelle, $\sigma(E,\theta=\text{const})$ is not a monotonic function of energy. Resonance-like changes in the differential cross section up to 50% and about 500 kev wide are seen near 15.0 and 17.6 Mev for all angles $\geqslant 80°$. These strong fluctuations with energy in the differential cross section also have been observed by other experimenters at lower energies.

* This work was supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.

I6. Multipole Mixtures of Gamma Rays from the $C^{13}(d,p_{3}\gamma)$ Reaction.* N. R. Fletcher, D. R. Tilley, and R. M. Williamson, *Duke University.*—The $C^{13}(d,p_{3}\gamma)$ angular correlation has been shown to be somewhat dependent on the incident deuteron energy for $E_d=2.80$, 3.23, and 3.70 Mev.[1] The angular correlation through the third excited state of C^{13} is found to be approximately energy-independent for these bombarding energies. Further, the angular correlation shows both axial symmetry and front-back symmetry. These features indicate little distortion in the formation of the 3.85-Mev state of C^{13}, a conclusion supported by the data of Chase *et al.*[2] If we assume that the simple Butler stripping theory may be applied, the following conclusions about the multipole mixtures of the gamma rays may be drawn: $\Gamma_\gamma(E3)/\Gamma_\gamma(M2)\sim 10^{-3}$ for the 3.85-Mev radiation; $0.05\leqslant\Gamma_\gamma(E2)/\Gamma_\gamma(M1)\leqslant 0.3$ for the 3.68-Mev radiation. The latter is an enhancement of $E2$ radiation by a factor of more than 50 times the Weisskopf approximation—a result in qualitative agreement with the enhancement of other $E2$ transitions in light nuclei.

* Supported in part by the U. S. Atomic Energy Commission.
[1] N. R. Fletcher, D. R. Tilley, D. Gerke, and R. M. Williamson, Bull. Am. Phys. Soc. Ser. II, 5, 450 (1960).
[2] L. F. Chase, Jr., R. G. Johnson, and E. K. Warburton, Phys. Rev. Letters 5, 399 (1960).

I7. Multibody Breakup of C^{12} by 22-Mev Alphas.* H. B. Knowles, Lynn B. Brown, and J. P. Stoering, *Lawrence Radiation Laboratory, Livermore.*—The alpha particles from a thin polystyrene target in a 22.2-Mev alpha-particle beam were accepted at 45° (lab angle), magnetically analyzed, and counted in a proportional counter. The counter was pulse-height analyzed to discriminate against other particles. Alpha particles of energies as low as 2 Mev could be counted. The center-of-mass alpha-particle momentum spectrum clearly shows peaks corresponding to the elastic 4.43-, 7.65-, and 9.61-Mev levels and smaller peaks corresponding to several levels between 10- and 13-Mev excitation. The continuum starting under the 7.65-Mev level has the characteristic shape of a four-body reaction, and, on the assumption of isotropy, the total cross section for $C^{12}+\alpha\rightarrow 4\alpha$ at this energy is about 300 mb.

* Work done under the auspices of the U. S. Atomic Energy Commission.

I8. Angular Distributions of the 0.75-Mev γ Ray from the $C^{14}(d,p\gamma)C^{15}$ Reaction and the 0.98-Mev γ Ray from the $Li^{7}(d,p\gamma)Li^{8}$ Reaction.* L. F. Chase, Jr., R. G. Johnson, F. J. Vaughn, and E. K. Warburton,† *Lockheed Missiles and Space Division Research Laboratory.*—Angular distribution measurements of the 0.75-Mev γ ray from the $C^{14}(d,p\gamma)C^{15}$ reaction and the 0.98-Mev γ ray from the $Li^{7}(d,p\gamma)Li^{8}$ reaction have been performed and interpreted from the point of view of a stripping mechanism near threshold.[1] Angular distributions of the 0.75-Mev γ ray from the $C^{14}(d,p\gamma)C^{15}$ reaction were measured from 0 to 150 degrees for $E_d=2.9$, 3.1, 3.2, and 3.4 Mev, and the γ-ray yield curve at 148 deg was obtained for deuteron energies between 2.7 and 3.5 Mev. The yield increased smoothly with energy in this region, and the shape of the observed angular distributions was nearly constant. The distribution at $E_d=3.2$ Mev was fitted adequately with $W(\theta)=1+(0.46\pm0.03)P_2(\cos\theta)-(0.15\pm0.03)P_4(\cos\theta)$. Angular distributions of the 0.98-Mev γ ray from the $Li(d,p\gamma)Li^{8}$ reaction were found to be isotropic within ±10% at $E_d=2.3$, 2.6, 2.9, and 3.1 Mev. Smoothly increasing 0.98-Mev γ-ray yields at 0 and 90 deg were observed for deuteron energies between 1.8 and 3.3 Mev. The assignments of $\frac{1}{2}^+$ to the 0.75-Mev level in C^{15} and 1^+ to the 0.98-Mev level in Li^{8} are discussed in connection with the experimental results.

* Supported jointly by the Lockheed General Research Program and the U. S. Atomic Energy Commission.
† Permanent address: Princeton University, Princeton, New Jersey.
[1] E. K. Warburton and L. F. Chase, Jr., Phys. Rev. 120, 2095 (1960); L. F. Chase, Jr., R. G. Johnson, and E. K. Warburton, Phys. Rev. 120, 2103 (1960).

I9. Excited States of N^{13} around 7 Mev.* N. M. Nikolic, L. J. Lidofsky, and T. H. Kruse, *Columbia University.*—The 57° (laboratory) excitation function and the angular distributions of gamma rays from the reaction $C^{13}(p,p',\gamma_{4.43})C^{13}$ were observed using the Pegram Nuclear Physics Laboratories Van de Graaff. A thin deposit of carbon on tantalum was used as target. The observations were made with a 3-in.×3-in. NaI(Tl) crystal mounted on a rotating arm outside the chamber. Besides the two previously observed[1] resonances at 5.37- and 5.90-Mev bombarding energy, a weak resonance at 5.68 Mev was observed. The same resonance was observed in the excitation curve of inelastically scattered protons.[2] The angular distributions were observed at twelve bombarding energies between 5.25 and 6.05 Mev, and the data were analyzed by means of least-square fit and compared with

calculated angular distributions. The parameters of the N^{13} states observed are

Bombarding energies (Mev)	J (π)	Γ_{lab} (kev)
5.37	3/2 (+)	130
5.68	1/2 (±)	~20
5.90	5/2 (+)	60

* This work partially supported by the U. S. Atomic Energy Commission.
[1] L. J. Lidofsky, J. L. Weil, R. D. Bent, and K. W. Jones, Bull. Am. Phys. Soc. Ser. II, 2, 29 (1957).
[2] H. Yoshiki and N. Nikolic, Bull. Am. Phys. Soc. Ser. II, 1, 46 (1960).

I10. Radiative Capture of Protons by N^{15}.* R. WEINBERG, H. DIESELMAN, C. NISSIM-SABAT, AND L. J. LIDOFKSY, *Columbia University.*—The radiative capture of protons by N^{15} must compete with several other highly prolific reactions and so is expected to take place only through states in O^{16} having spin-parity 1+, 1−, or 2+. The position and relative strengths of capture into 1− states has been discussed by Brown.[1] The region of excitation of O^{16} between 13 and 18 Mev has been investigated by the $N^{15}(p,\gamma)$ reaction. Angular distributions of the capture radiation at each of the observed resonances have been measured. These distributions are interpreted in terms of the spin and parity of each state as well as the reduced widths for formation in terms of the possible single particle states.

* This work partially supported by the U. S. Atomic Energy Commission.
[1] G. E. Brown and M. Bolsterli, Phys. Rev. Letters 3, 472 (1959).

I11. Angular Distributions and the Total Cross Section for the $N^{15}(p,n)O^{15}$ Reaction.* A. SAYRES, D. LISTER, AND D. LIGHTBODY, *Columbia University.*—Angular distribution and total cross-section measurements have been made for the neutrons produced in the $N^{15}(p,n)O^{15}$ reaction from the threshold energy to the energy of the first resonance at 4.4 Mev. A He^3 filled proportional counter was used as the neutron detector. This detector has the advantage of being free of the background and efficiency uncertainties of some previous measurements on this reaction.[1] The angular distributions were taken with the counter subtending an angle of 8 deg with respect to a gas-filled target of N^{15}. The total cross section was measured by observing the annihilation radiation following the positron decay of O^{15} using a NaI detector. Some implications of these measurements will be discussed.

* This work partially supported by the U. S. Atomic Energy Commission.
[1] J. L. Weil, Thesis, Columbia University, CU-180 (1958).

I12. $N^{14}(p,n)N^{13}$ and $N^{15}(p,p2n)N^{13}$ Reactions Induced by Protons of Energy 0.4 to 6.2 Gev.* SAMUEL S. MARKOWITZ AND LINDA CHANG SAH, *University of California, Berkeley.*—Cross sections have been measured for 10-min N^{13} production from N^{14} and N^{15} in boron nitride powder targets. Decay of the N^{13} positron-emitter was followed with an end-window methane-gas flow proportional counter. Decay curve analysis by IBM-704 computer was used to separate the N^{13} activity from the 20.5-min C^{11} which was also produced in the bombardments. The individual measurements (in mb) are given in Table I.

TABLE I.

E_p (Gev)	0.4	0.6	0.72	2.0	4.1	6.2
$N^{14}(p,pn)N^{13}$	5.2, 5.3	4.1, 5.4	3.8, 4.1, 4.6	5.1	5.6, 5.7	4.8, 4.8
$N^{15}(p,p2n)N^{13}$	1.8, 2.4	1.9, 2.4, 2.7	2.3, 3.1	1.7, 2.0	3.3, 3.5, 3.7	2.2, 2.2

The N^{13} production cross sections are lower than those for other similar high-energy processes. The mechanism for the (p,pn) reaction is thought to be a "knock-on" and that for $(p,p2n)$ a knock-on followed by neutron evaporation. In the special case of N^{13}, all the excited states are unstable towards proton emission, and only the direct formation of the 10-min ground state is observed.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

THURSDAY MORNING AT 9:30

Statler-Hilton, Terrace Ballroom West

(BENJAMIN LAX presiding)

Semiconductors II (Elements, Theory)

IA1. Photo and Thermal Effects in Compensated Zinc-Doped Germanium. R. J. KEYES, *Lincoln Laboratory.**—At low temperatures zinc-doped germanium exhibits a number of rather unusual photo and temperature effects when the lower zinc levels have been filled by electrons from compensating antimony impurities but the higher energy levels are only partially filled. These effects include negative photoconduction, a discontinuity in the temperature dependence of the sample resistivity, and storage of free electrons produced by radiation of greater energy than the semiconductor gap. Similar phenomena have been observed to a much lesser degree in other semiconducting materials.[1] Although the behavior is quite complex, a qualitative theory which explains all the observations will be presented. A quantitative fit between theory and data exists for those areas where numerical results are available.

* Operated with support from the U. S. Army, Navy, and Air Force.
[1] W. W. Tyler and R. Newman, Phys. Rev. 98, 961 (1955).

IA2. Effect of a Constant Electric Field on Germanium Fast Surface States. Y. MARGONINSKI,* *Brown University* (introduced by W. C. Dunlap).—The experimental evidence regarding the effect of electrical fields on the fast states of germanium is, at present, contradictory: Litovchenko and Lyashenko[1] explained their experimental results by assuming that the fields affect only the density of states but not their energy. This would support the current view on charge transfer through the semiconductor oxide layer. Rzhanov *et al.*,[2] on the other hand, reported field-induced changes in energy as well as density. To resolve this question, careful measurements of surface recombination velocity and surface conductivity were performed before and after application of dc fields of about 2×10^6 v/cm. Though the effect of the field on the surface state density was much smaller than that found by the Russian scientists, the experimental results indicated clearly that the energy and ratio of capture cross sections were indeed unaffected by the field. It was also found that in wet ambients the ac field shifted the unperturbed surface potential by more than $+5kT$.

* On leave from the Department of Physics, Hebrew University, Jerusalem, Israel. Present address: Research Laboratory, Raytheon Company, Waltham, Massachusetts.
[1] V. G. Litovchenko and V. I. Lyashenko, Soviet Phys.—Solid State 1, 1470 (1960).
[2] A. V. Rzhanov, N. M. Pavlov, and M. A. Selezneva, Soviet Phys.—Tech. Phys. 3, 2419 (1958).

IA3. Surface Dependence of the Thermoelectric Power in Germanium at Room Temperature: Experimental. J. N. ZEMEL, *U. S. Naval Ordnance Laboratory.*—A series of experiments have been conducted to determine the dependence of thermoelectric power on the excess charge in the surface space charge region in the room temperature range. The experiments were carried out on a thin sample of very pure intrinsic germanium, and gas ambients were used to vary the surface space charge. Extreme care was taken to reduce or eliminate spurious thermal gradients in the apparatus. The reproducibility of the data indicated that the apparatus was adequate. The temperatures at which measurements were carried out were from 15°C to 35°C. A 1.5°C temperature difference was used to produce the thermal emf. Comparison of the experimental results with the theoretical predictions of Greene[1] gave remarkably good agreement. Unfortunately, the role of the surface scattering mechanism in the experimentally achievable range of surface potential increments was not great enough to provide a clear proof of the scattering's existence, let alone its magnitude. At lower temperatures, the surface thermoelectric power may have some interesting applications to the study of phonon scattering at surfaces.

[1] R. F. Greene, following abstract.

IA4. Surface Dependence of the Thermoelectric Power in Germanium at Room Temperature: Theoretical. R. F. GREENE, *U. S. Naval Ordnance Laboratory.*—A Boltzmann equation treatment is given of the thermoelectric effects[1] associated with excess carriers in the surface space charge region (SSCR) of a semiconductor. In the SSCR, potential variations $\gg kT$ within a mean free path are common so that conductance, thermoelectric power, etc., are nonlocal transport quantities. When these are properly defined, however, the Boltzmann equation treatment of them satisfies the Kelvin-Onsager relation. Constant relaxation times and spherical energy surfaces are assumed to reduce the labor of evaluating the transport integrals. These integrals remain complex because no approximations have been made in the solution of the Poisson equation for the shape of the SSCR. The resulting integrals, which are similar to those arising in the theory of surface mobilities,[2] have been evaluated by electronic computer for various surface scattering conditions and for a range of bulk conditions corresponding to near-intrinsic germanium near room temperatures. Under these conditions the resulting thermoelectric power vs surface conductance curves are unfortunately rather insensitive to the degree of specularity of the surface.

[1] J. N. Zemel, preceding abstract.
[2] R. F. Greene, D. R. Frankl, and J. N. Zemel, Phys. Rev. **118**, 967 (1960).

IA5. Magneto-Surface Measurements on Germanium at Dry-Ice Temperatures. E. J. SCOTT AND J. N. ZEMEL, *U. S. Naval Ordnance Laboratory.*—Recently, Greene, Frankl, and Zemel[1] investigated the dependence of the effective conductivity mobility in surface space charge regions on the ratio L_D/λ, where L_D is the intrinsic Debye length and λ is the carrier mean free path. The dependence of the mobility on the surface potential increment decreases with increasing values of this ratio. When the ratio reaches values $L_D/\lambda \geq 500$, the conductivity mobility becomes essentially independent of any attainable surface potential change. A series of magneto-surface measurements using the methods of Zemel and Petritz[2] was carried out on very pure germanium at dry-ice temperatures. At these temperatures for this material L_D/λ becomes greater than 500 because of the increase in L_D with temperature through the exponential change in the intrinsic carrier concentration, whereas λ remains nearly constant. The results on the Hall mobility substantially confirm the theoretical predictions when the carrier concentration is varied by a factor of five. However, the magnetoresistance varied somewhat, indicating some diffuse scattering.

[1] R. F. Greene, D. R. Frankl, and J. N. Zemel, Phys. Rev. **118**, 967 (1960).
[2] J. N. Zemel and R. L. Petritz, Phys. Rev. **110**, 1263 (1958).

IA6. Band Structure of Heavily Doped Germanium. H. SCHLOSSER, *General Telephone and Electronics Laboratories.*—It is well known that the addition of large concentrations of impurities to a semiconductor changes the band structure. We have investigated the changes in the band structure of Ge upon the addition of columns III and V impurities using perturbation theory[1] and the simple model of the band structure. Energy vs wave vector (k) and density of states vs k curves have been obtained for a number of impurity concentrations in the range 10^{18}/cm^3 to 5×10^{20}/cm^3. It is found that, relative to the pure material, the band edge shifts and the density of states and energy curves change in shape. In the density-of-states and energy curves for the perturbed crystal, tails are found at the band edges that correspond to a much lower effective mass than is characteristic of the unperturbed crystal. At impurity concentrations appreciably lower than 10^{18}/cm^3, one has discrete impurity level, and the perturbation theory diverges. These results have been applied to a calculation of the elastic tunneling current in Esaki diodes.

[1] R. H. Parmenter, Phys. Rev. **104**, 22 (1956).

IA7. Measurement of the Galvanomagnetic Effects in Moderately Doped Tellurium. W. B. TEUTSCH, H. ROTH,* AND H. T. HARPER, *General Atomic.*—Measurements of the type previously made on pure tellurium[1] have been carried out on moderately doped tellurium. Oriented samples, with their long axis either parallel to or perpendicular to the c axis, were taken from a Czochralski-grown single crystal.[2] The two resistivities, two Hall coefficients, and eight magnetoresistance coefficients were studied from 70°K to 300°K in magnetic fields up to 13 kgauss. The samples are extrinsic and p-type in this entire range. As was anticipated, the present results differ from the work on pure tellurium[1] and—being free of the anomalies exhibited by the latter—are perhaps more indicative of the properties of the valence band. The two Hall coefficients have the same value and indicate a carrier density of $\sim10^{17}$ cm^{-3}. The most striking feature is the vanishing of $\rho_{11,33}$, its value being about 100 times smaller than other corresponding coefficients. This unusual result seems to preclude any straightforward explanation of the conduction processes in the valence band.

* Now at Research Division, Raytheon Company, Waltham, Massachusetts.
[1] H. Roth, J. Phys. Chem. Solids **8**, 525 (1959). See also H. Roth, Doctoral Dissertation, University of Pennsylvania (1959) or General Atomic report GA-791.
[2] Kindly supplied by T. J. Davies and G. D. Long, Honeywell Research Center, Hopkins, Minnesota.

IA8. Galvanomagnetic Coefficients of Ga Single Crystals at 77°K.* W. A. REED AND J. A. MARCUS, *Northwestern University.*—Resistance, longitudinal and transverse magnetoresistance, Hall effect, and Planar Hall effect measurements have been continued[1] on Ga single crystals ($\rho_{4.2}/\rho_{273}=1\times10^{-4}$), and the remaining 12 of the 18 nonzero coefficients to the order B^2 in a phenomenological equation have been specified at 77°K. Rotation and field dependence curves were taken, and they indicate that coefficients for powers of B greater than two are negligible for $B<10$ kgauss. To make the measurements as self-consistent as possible, crystals of square cross section were made and mounted so that only three crystals (current along the three mutually perpendicular axes) were needed to specify all the coefficients.

* Supported by the National Science Foundation.
[1] J. Yahia and J. A. Marcus, Phys. Rev. **113**, 137 (1959).

IA9. Electron Emission from Uncesiated *p-n* Junctions in Silicon.* N. SCLAR, *Nuclear Corporation of America.*—Electron emission from *p-n* junctions in silicon has been reported[1] in which cesium is introduced into a tube containing the silicon. The cesium treatment reduces the silicon work function so that electrons formed in the avalanche condition of the back biased junction can emerge from the surface. The use of free cesium introduces undesirable effects related to its high vapor pressure, its ready ionization, and its low resistance. To retain the low work function properties without its defects, the role of cesium as an impurity in silicon has been investigated by vapor diffusion studies. Cesium is a donor with a diffusion constant at 1100°C of 5×10^{-11} cm²/sec and a solubility in the range of 10^{19}/cm³. *p-n* junctions formed by diffusing cesium into *p* type silicon exhibited well-behaved electrical properties. Electron emission at a level of 10^{-9} amp has been observed from such a junction in which the diffused layer was subjected to a light sandblasting treatment. This treatment is believed to have uncovered low work function *p-n* junction emitting areas. This emission current is some 10^4 times that previously observed[2] from uncesiated junctions.

* Work supported by the Bureau of Ships.
[1] J. A. Burton, Phys. Rev. 108, 1342 (1957); W. E. Spicer, Bull. Am. Phys. Soc. Ser. II, 5, 69 (1960).
[2] B. Senitzky, Phys. Rev. 116, 874 (1959).

IA10. Photothermal (PT) Effect in Semiconductors. W. W. GÄRTNER, *CBS Laboratories*, AND H. METTE AND C. LOSCOE, *U. S. Army Signal Research and Development Laboratory.*—When a sample of semiconducting material is illuminated with photons of sufficient energy, electron-hole pairs are generated which diffuse through the crystal from the place of their generation to regions of lower excess-pair concentration. Each pair transports an amount of energy approximately equal to the band separation, thus contributing to the thermal conductivity. This energy is deposited where the pair undergoes nonradiative recombination, increasing the local (measurable) temperature of the crystal. A nonuniform temperature distribution therefore is established in the sample which depends on the nature of the incident radiation, on the characteristics of optical absorption, on the bulk and surface recombination mechanisms, on the boundary conditions for temperature and energy flux and on the ordinary thermal conductivity of the material. This establishment of a temperature distribution in a solid by optically excited diffusing and recombining carriers and the attendant modification in the thermal conductivity is called the Photothermal (PT) Effect. It is the thermal analog to the Dember effect. Its deflection by a magnetic field is called the Photomagnetothermal (PMT) Effect. A simple theory of the PT effect is presented which appears applicable to germanium and silicon. Experimental problems are discussed.

IA11. An Alternative Approach to the Solution of Added Carrier Transport Problems in Semiconductors.* J. P. MCKELVEY, T. P. BRODY, AND R. L. LONGINI, *Westinghouse Research Laboratories.*—A novel method of solving added carrier transport problems in semiconductors is presented. The usual procedure in treating such problems is to derive a continuity equation for carrier concentration (assuming carrier conservation after allowing for generation and recombination) and to solve this equation under appropriate boundary conditions. Net fluxes are obtained from diffusion and drift current equations which involve concentrations and gradients. In the new formulation, equations embodying flux conservation (again allowing for generation and recombination), which incorporate boundary conditions from the outset, are solved in the steady-state, one-dimensional case, giving a Green's function for the desired carrier flux directly. The method is more general than the continuity equation formulation in that the dimensions of the system and the diffusion lengths need not be large compared to the mean free path; in particular, it is unnecessary to assume Fick's law for diffusion. Otherwise, the method is equivalent to the continuity equation analysis. An example involving carrier generation in a region bounded by a plane surface of arbitrary reflection coefficient (recombination velocity) and by a parallel collecting junction is worked out.

* Supported by the U. S. Air Force, Wright Air Development Division.

IA12. Electron Transport in a Semiconductor. H. L. FRISCH, *Bell Telephone Laboratories*, AND JOEL L. LEBOWITZ,* *Yeshiva University.*—We investigate the linear transport properties of electrons in a semiconductor-like solid when both phonon and impurity scattering are important. The problem is treated for the case where Maxwellian statistics apply, and the electrons are described by a classical distribution function in position and velocity, $f(r,v)$ satisfying a linear, space-dependent Boltzmann equation. This equation is solved formally in the presence of a weak external electric field in a form convenient for perturbation expansions in the relative strength of the different scattering mechanisms, some of which are carried out explicitly. For the special simplified model where the lattice scattering is represented by a single relaxation time, the change in conductivity due to the addition of impurities may be shown by use of the Wiener-Khinchin theorem to be always negative. In general the magnitude of the first-order change in the conductivity, in powers of the phonon relaxation time, will depend markedly on the sign of the impurity potential. Extension of these results to the case where the electrons are described by a single-particle density matrix also will be discussed.

* Supported by the U. S. Air Force Office of Scientific Research.

IA13. Diffusion of Charged Particles into a Semiconductor under Consideration of a Built-In Field. KURT LEHOVEC AND ALEXIS SLOBODSKOY, *Sprague Electric Company.*—Solutions will be presented for the impurity distribution in a semiconductor arising from indiffusion and taking into account the electric field due to the diffusing impurities. If the surface concentration of the impurities exceeds the intrinsic carrier concentration at the diffusion temperature, large corrections are required to the apparent surface concentration obtained by extrapolating from the tail of the impurity distribution to the surface, using a complementary error function, i.e., ignoring the electric field enhancing diffusion. The flow of impurities in the electric field can be accounted for by an effective diffusion constant which varies with concentration[1] and considering then a flow of impurities by diffusion only. We have chosen an explicit space-dependent zero-order approximation containing two parameters for the effective diffusion constant, then integrated Fick's law to obtain a first-order approximation of the impurity distribution, and then determined the two parameters to approach a self-consistent fit between the effective diffusion constant calculated from the first-order solution of the impurity distribution and the zero-order approximation. A self-consistency better than 4% was achieved over the entire range of positions.

[1] F. M. Smits, Proc. Inst. Radio Engrs. 46, 1049 (1958).

IA14. Pressure Theory of the Thermoelectric and Photovoltaic Effects. MILTON GREEN, *U. S. Army Signal Research and Development Agency.*—The diffusive force, Fick's plus Soret's,[1] is identified as a pressure gradient. This leads to the following potentials: π, P, and G defined by grad $\pi_p=(ep)^{-1}\times$ grad P_p and $G_p=V+\pi_p$, where P_p is an effective hole pressure, e the electronic charge, p the hole concentration, and V the electric potential. Hole current density I_p is given by $I_p=-ep\mu_p$ grad G_p. Identical expressions exist for electrons except that e and μ_n are negative. For isothermal equilibrium $I_p=I_n=0$; hence $G=$constant. For *open circuit*, irreversible-

steady-state, $I=0$ and $I_p=-I_{n\varphi 0}$; hence the steady-state electric field is $E=(\text{grad } P_p-b \text{ grad } P_n)\mu_{p\varphi}\rho$, where ρ and b are, respectively, resistivity and carrier mobility ratio. If $P_p=pkT$ and $P_n=nkT$, then the potential for isothermal pair-injection (photo) is $V=(b-1)(b+1)^{-1}e^{-1}kT \ln(\rho_0/\rho)$; ρ_0 is the equilibrium resistivity. When the pressure gradients are the consequence of a temperature gradient, the expression for E yields for the thermoelectric power:

$$Q=k[d(pT)/dT-bd(nT)/dT]\rho\mu_p.$$

Phonon interaction gives rise to additional current components given by $I_p=-\mu_{p\phi}$ grad P_φ and $I_n=\mu_{n\varphi}$ grad P_φ; $\mu_{p\varphi}$ and $\mu_{n\varphi}$ are the interaction mobilities and P_φ is the phonon effective pressure. The Einstein relationship is satisfied provided $P_p=pkT+f(T)$; $f(T)$ is a function of T only.

[1] F. W. G. Rose *et al.*, J. Electronics and Control **3**, 481 (1957).

IA15. Electron Mobility in Semiconductors under the Combined Influence of Impurity and Lattice Scattering. ALLAN ANDERMAN AND HOWARD REISS, *Atomics International.*—The combined effect of impurity and lattice scattering on electron mobility in semiconductors has been investigated using a Boltzmann-like equation developed in an abstract electron-ion pair space. It is assumed that each electron experiences only that Coulomb field due to the ion which is its nearest neighbor at any given moment. This technique enables one to develop a Boltzmann-like equation which replaces the the effects of a random array of scatterers by the Coulomb field arising from a single ion and which, moreover, contains only one collision term, namely, that due to electron-phonon interaction. The effect of the ion appears as an acceleration in the streaming operator. An additional term appears in the equation to account for the fact that in the course of its passage a moving electron will change nearest neighbors, thereby giving rise to a discontinuous change in the position of the electron relative to its immediate nearest neighbor. The modified Boltzmann equation has been solved in a power series in the phonon relaxation time. The effect of the impurity is first observable in the third-order term in this series. Solutions for the fourth-order term also are given.

THURSDAY MORNING AT 9:45

Statler-Hilton, Terrace Ballroom East

(R. M. WALKER presiding)

Electron Physics; Irradiation Effects; Lattices

J1. Photodetachment Cross Section for Atomic Carbon Negative Ions.* M. SEMAN, M. A. FINEMAN,† AND L. M. BRANSCOMB, *National Bureau of Standards.*—A new hot cathode arc negative ion source and a bakeable crossed-beam photodetachment apparatus incorporating an electron multiplier permit the investigation of photodetachment cross sections of many ions not previously studied. The ion source contains a tungsten filament, a weak axial magnetic field, and a series of insulated, floating disks with center holes which are progressively smaller as one approaches the 1-mm diam anode aperture. Run at 400 ma in 50 μ of CO, the discharge yields up to 3×10^{-9} amp of C^- out of a total of over 1 μamp of negative ion current. The photodetachment apparatus[1] was modified to permit bakeout and electron multiplier detection of post-accelerated electrons. The unfiltered light from a carbon arc lamp now yields photodetachment signals from negative ion currents (of H^-) as small as 2×10^{-11} amp. Preliminary studies of the C^- spectrum, whose form was predicted by Smith,[2] give a cross section of $1.3\pm0.3\times10^{-17}$ cm^2 near 4620 A.

* Supported in part by the Office of Naval Research.
† Permanent address: Providence College, Providence, Rhode Island.
[1] S. J. Smith and L. M. Branscomb, Rev. Sci. Instr. **31**, 733 (1960).
[2] S. J. Smith, *Proceedings Fourth International Conference on Ionization Phenomena in Gases*, N. R. Nilsson, editor (North Holland Publishing Company, Amsterdam, 1960), p. IC 219.

J2. On the Correction of Electron Lenses. T. A. WELTON AND J. KRONSBEIN,* *Oak Ridge National Laboratory.*—The objective lens of a conventional electron microscope consists of a static, axially symmetric magnetic field with electrons confined to trajectories near the axis (paraxial assumption). It is well known that for such a lens the lowest order spherical aberration which is in principle possible is actually of definite sign. This essential spherical aberration operates in practice to make the minimum resolvable distance considerably greater than a typical atomic spacing by restricting the numerical aperture to values between 0.01 and 0.001. A new type of lens, the annular objective, is being studied in hopes that this aperture limitation can be relaxed. In annular optics, the conventional paraxial assumption is abandoned, thereby making all computations much more difficult. Although a trivial calculation suffices to demonstrate the definite sign of the aberration in conventional systems, no calculation of such simple type allows demonstration of a similar limitation in the annular case, and such arguments seem in fact to indicate that correction of the annular objective actually is possible. Detailed machine computations of the trajectories through a simple annular system are in progress, and a definite decision is being sought.

* Summer employee during 1960 from the University of Florida.

J3. Electric Potential Distributions in a Streaming Plasma.* M. FERENTZ, *General Atomic and St. John's University,* AND W. B. TEUTSCH, *General Atomic.*†—The operation of a cesium cell for low cesium pressures may be idealized to a thermionic diode with no space charge.[1] Some insight into the space charge neutralization by positive ions may be obtained by studying the electric potential in such a diode.[2] We consider the cathode surface to emit electrons and ions. We neglect collisions so that the motion of the particles is determined solely by the (self-consistent) electric potential. For intermediate cathode-anode potential differences, the ions and electrons form an almost neutral streaming plasma which reproduces the most striking feature of an equilibrium plasma, namely the absence of an electric field in its interior. For small cathode-anode potential difference, a streaming plasma with a spatially oscillating electric field is obtained. We have examined certain critical electric potential distributions for a wide range of ion-to-electron ratio. The voltage-current characteristics for the present model differ somewhat from the ideal case in the vicinity of the "knee."

* Supported in part by the Rocky Mountain—Pacific Nuclear Research Group and by the San Diego Gas & Electric Company.
† Abstract separated from those on plasma physics at the authors' request.
[1] Hernqvist, Kanefsky, and Norman, RCA Rev. **19**, 255 (1958).
[2] P. L. Auer and H. Hurwitz, Jr., J. Appl. Phys. **30**, 161 (1959).

J4. One-Species Analyses of Drift and Diffusion Contributions to Photocurrents and Their Interrelation. G. K. LINDEBERG, *Minnesota Mining and Manufacturing Company.*—A method is proposed for studying photoconductivity in systems where very little is known at the outset about the natures of the current carrying species and the mechanisms governing their transport and recombination. Independent species contributions are introduced abstractly as being quantities which obey continuity equations and which determine variations of conductivity and emf. It is reasonable to use a minimal number of these species. In this paper a one-species analysis is developed. This suggests a sequence of two specific experiments, criteria for consistency of the one-species analysis within the experimental context, and possible directions of microscopic interpretation. The conductivity, emf, and recombination can be determined as functions of the species if analysis is consistent. The diffusion coefficient is obtainable, but the effective mobility is not completely specified in the experimental context. If the species are electronic carriers, and if the emf is identifiable with their Fermi level, the distribution of electronic states is available as the solution of an integral equation.

J5. Polarized Luminescence of Calcium Fluorophosphate. PETER D. JOHNSON, *General Electric Research Laboratory.*—The luminescence of synthetic single crystals of apatite, $3[Ca_3(PO_4)_2]\cdot CaF_2$, activated with Sb^{+3} and Mn^{+2}, is spontaneously polarized when excited with unpolarized 2537 A or 1850 A radiation. The luminescence due to manganese is completely polarized with its electric vector parallel to the crystal c axis. Antimony luminescence is partially polarized perpendicular to the c axis. These results lead to the conclusion that luminescent manganese substitutes for calcium in the "CaI" position. This site is on a trigonal symmetry axis which is parallel to the c axis of the apatite structure.[1] Most, if not all, of the luminescent antimony substitutes for calcium which is in reflection plane perpendicular to the c axis. This "CaII" site is one of low symmetry adjacent to a fluoride and 5 oxygen atoms. The effect on the emission spectra of substituting chloride for fluoride and the electron spin resonance of Mn^{+2} in apatite can be correlated with these results. Qualitative conclusions as to the nature of the states involved in antimony luminescence can be deduced from the polarization measurements and other optical data.

[1] St. Naray, Szabo Z. Krist **75**, 394 (1930).

J6. Temperature Dependence of Bombardment-Induced Conductivity. W. C. SCHIEVE* AND M. A. POMERANTZ, *Bartol Research Foundation.*—Measurements[1] of the temperature dependence of the conductivity induced in MgO by 1.3-Mev electrons have been extended to 100°K. A maximum occurs near 250°K. The results were consistent with a $T^{3.3}$ law over the range 107°–190°K. Furthermore, the dependence of the crystal current I_c upon the primary beam current I_p is linear both at high and low temperature. The dependence of I_c is linear both at high and low temperature. The dependence of I_c upon applied potential V_a also was investigated. In one sample, the increase of I_c with V_a was slightly more rapid than linear. At low temperature, the effect is more pronounced, the conductivity departing from ohmic behavior at 3×10^4 v/cm. It is impossible to ascribe the temperature dependence of the bombardment-induced conductivity solely to the temperature variation of carrier mobility. The results can be explained in terms of the temperature variation of both lifetime and carrier mobility. A combination of optical mode (polaron), acoustical mode, and ionized impurity scattering is assumed, as well as temperature-dependent capture cross section for the carrier. A theoretical fit of the bombardment-induced conductivity vs temperature gives reasonable values for the parameters.

* Present address: U. S. Naval Radiological Defense Laboratory, San Francisco, California.
[1] J. F. Marshall, M. A. Pomerantz, and R. A. Shatas, Phys. Rev. **106**, 432 (1957).

J7. Enhanced Thermal Expansion Coefficient in X-Rayed NaCl.* M. F. MERRIAM,† D. A. WIEGAND, AND R. SMOLUCHOWSKI,‡ *Carnegie Institute of Technology.*—Additional results have been obtained on the enhancement, reported earlier,[1] of the thermal expansion coefficient of rocksalt irradiated with penetrating x rays. The fractional increase in expansion coefficient $\Delta\alpha/\alpha$ is roughly proportional to the defect concentration n/N as measured by the fractional volume expansion $\Delta V/V$. If $n/N=\Delta V/V$, then $\Delta\alpha/\alpha\approx14(n/N)$. Thermal annealing of $\Delta\alpha/\alpha$ proceeds roughly simultaneously with the annealing of $\Delta V/V$. The increase in expansion coefficient is apparently insensitive to the electronic state of a lattice defect. Although understanding of the effect is incomplete, the sign and order of magnitude of $\Delta\alpha/\alpha$ is given by thermodynamic arguments.

* Research supported by the U. S. Atomic Energy Commission and the Office of Naval Research.
† Now at General Atomic, La Jolla, California.
‡ Now at Princeton University, Princeton, New Jersey.
[1] M. F. Merriam, D. A. Wiegand, and R. Smoluchowski, Bull. Am. Phys. Soc. Ser. II, **5**, 185 (1960).

J8. Thermoluminescence of Sodium Chloride Irradiated with 40-Mev Alpha Particles. C. GIAMATI, G. ALLEN, AND M. HACSKAYLO.—The effect of 40-Mev alpha particles on NaCl crystals has been investigated by means of post-irradiated thermoluminescence measurements. A possible mechanism is suggested to account for the results. The suggested interpretation of the results allows a partial separation to be made of the effects of atomic displacement from the effects of ionization. The explanation appears to be consistent with diverse other investigations of alkali halides.

J9. Mechanism for the Production of Interstitials in KCl by X Rays at Low Temperatures.* R. E. HOWARD,† S. H. VOSKO,‡ AND R. SMOLUCHOWSKI,§ *Carnegie Institute of Technology.*—It is proposed that halogen vacancies and interstitials are formed in KCl by x rays at low temperatures through multiple ionization of the halogen ions. The positive halogen ion collides with one of the neighboring negative ions forming a Cl^+Cl^- molecule. The repulsive state of a normal Cl_2 molecule intersects this state near its energy minimum and leads to a de-excitation exchange. This permits the conversion of the high electronic excitation energy into several ev of kinetic repulsive energy which is sufficient to form, by means of a series of focused collisions, a halogen vacancy (F center) and an interstitial (H center) a considerable distance away as required by experiment. The efficiency of multiple ionization (Auger effect) is estimated and found to be in good agreement with the experiment.

* Supported by U. S. Atomic Energy Commission and Office of Naval Research contracts.
† Now at the National Bureau of Standards.
‡ Now at McMaster University, Hamilton, Ontario.
§ Now at Princeton University, Princeton, New Jersey.

J10. Determination of the Maximum Lattice-Chain Energy from Sputtering Yield Curves. DON E. HARRISON, JR., *University of Toledo.*—An analysis is presented which suggests that the "ankle energy," that is, the energy at which the experimental sputtering ratio curve begins to form a low energy tail, is the maximum energy which the metallic lattice can propagate in a close-packed direction. The effect appears to depend only upon the existence of a chaining threshold and not upon the mathematical model of the sputtering process. The equivalence is demonstrated for the author's statistical

model and for the primary lattice ion model of Kinchin and Pease.

J11. Derivation of the Five Two-Dimensional Bravais Lattices. JOHN R. MADIGAN, *Borg-Warner Corporation.*—The possible symmetry operations in a two-dimensional lattice are rotations about an axis perpendicular to and mirror reflection across a line in the plane of the lattice. The effect of either type of symmetry operation on a given set of basis vectors is to transform them into another set of possible basis vectors for the lattice. To be compatible with the requirement of translational symmetry in the lattice, the second set of basis vectors must be expressible as linear combinations of the first set with integral coefficients. This requirement restricts the allowed rotations and the types of lattices that can have mirror lines for elements of symmetry. It is possible to give a rigorous and yet simple treatment of the problem which not only deduces the allowed rotations but also the possible axial ratios and inter-axial angles. The method is applied to two-dimensional lattices and used to derive the five two-dimensional Bravais lattices. The extension to three-dimensional lattices is discussed.

J12. Anharmonic Attenuation of Localized Lattice Vibrations. P. G. KLEMENS, *Westinghouse Research Laboratories.*—Lattice modes localized about defects can interchange energy with the continuum of lattice waves by anharmonic interactions. The relaxation time of a localized mode is calculated, taking account of cubic anharmonicities and using perturbation theory analogous to the treatment of three-phonon interactions. At zero temperature the relaxation time is typically of the order of 100 periods but decreases with increasing temperature.

J13. Surface Vibrational Waves in Crystal Lattices with Complex Interatomic Interactions. D. C. GAZIS AND R. HERMAN, *General Motors Corporation*, AND R. F. WALLIS, *U. S. Naval Research Laboratory.*—The investigation of surface vibrational waves in crystal lattices is complicated by the necessity for satisfying the free boundary conditions at the surface. If the interatomic interactions include next-nearest neighbor interactions, next-next-nearest neighbor interactions, etc., the number of equations specifying the free boundary conditions may become rather large. A method has been developed which enables one in principle to satisfy the free boundary conditions when interatomic interactions of various ranges are included. Illustrative calculations of the frequencies and attenuation constants for surface waves in monatomic and diatomic linear chains with nearest and next-nearest neighbor interactions will be given. The application of the mathematical techniques to the evaluation of certain types of determinants will be discussed.

THURSDAY MORNING AT 9:45

New Yorker, Panel Room

(HOWARD REISS presiding)

General Physics

JA1. Molecular Pumps for Producing High Vacua.* C. E. WILLIAMS AND J. W. BEAMS, *University of Virginia.*—In order to produce the lowest pressure in a vacuum system it is important to bake out the system including the final stages of the pump. Completely bakeable molecular pumps have been developed.[1] The steel rotors are magnetically suspended inside of vacuum chambers made of nonferromagnetic materials such as glass or stainless steel. They are spun by rotating magnetic fields produced by field coils located outside the chamber. The stators are made of nonferromagnetic material which may be degassed by baking. Operational data will be given including ratios of the pressures on the high to the low sides of the pump and pumping speeds as a function of the clearance between rotor and stator, depth and shapes of grooves, and the peripheral speed of the rotor. Pressure ratios of over 10^4 and pumping speeds of a few liters/sec are not difficult to obtain. The fore pumping system consists of the usual rotary oil pump, diffusion pump liquid nitrogen trap series arrangement.

* Supported by Navy Bureau of Weapons and U. S. Army Office of Ordnance Research.

[1] J. W. Beams, Science **130**, 1406 (1959).

JA2. Pressure-Modulated Infrared Emission Spectra of Nitrous Oxide.* RICHARD R. PATTY† AND DUDLEY WILLIAMS, *The Ohio State University.*—A device for producing periodic variations in the volume of a gas sample has been developed. At a frequency of 8 cps the processes occurring within the sample are approximately adiabatic; consequently, sample temperature can be computed as a function of compression ratio c and the ratio γ of the specific heats of the gas. The range of temperature variation is sufficiently large to make it possible to observe the infrared emission spectra of various gases. Emission spectra of nitrous oxide in the vicinity of the 1167 cm^{-1}, the 1285 cm^{-1}, and the 2222 cm^{-1} vibration-rotation bands have been observed for various compression ratios. By addition of certain nonabsorbing gases, it is possible to obtain various effective values of γ. The observed integrated emission of each band as a function of the partial pressure of nitrous oxide is discussed and compared qualitatively with predictions based on integrated band absorption.

* Supported in part by the U. S. Air Force Cambridge Research Center.
† National Science Foundation Graduate Fellow.

JA3. Electronic States of F_2. A. AMITH,* *Harvard University.*—ASMO and "Atoms in Molecules"[1] schemes were employed to calculate the electronic levels of F_2—represented as a 14-electron system with nuclei of charges +7 eu. After allowing electronic promotions among the $n=2$ molecular orbitals and neglecting spin-orbit degeneracy, there resulted 44 terms of 14 distinct symmetry groups. In the primitive configurational calculation, ASMO predicted a nonbinding ground state ($^1\Sigma_g^+$), whereas AIM predicted a binding one. With full C. I., both predicted stable ground states, but the binding energies were overestimated (exptl.: 1.65, ASMO: 4.16, AIM: 8.30 ev) at an equilibrium internuclear distance ρ_E which was underestimated (exptl.: 141, ASMO and AIM: 1.16 A). Some excitation energies at the experimental ρ_E are

	ASMO: primitive/ with C.I.		AIM: primitive/ with C.I.		Exptl.
$^3\pi_u$	3.00	2.64	3.51	3.18	3.16 ev
$^1\pi_u$	4.70	3.88	5.01	4.72	4.28
$^1\Sigma_u^+$	19.70	13.51	14.72	11.85	11.96

The effects of the ionic character of the atomic species upon

the resulting molecular terms, and the validity and applicability of the calculations, will be discussed.

* Now at the RCA Laboratories, Princeton, New Jersey.
[1] W. E. Moffitt, Proc. Roy. Soc. (London) **A210**, 245 (1951).

JA4. Absorption Coefficient of Beryllium in the Vicinity of the *K* Edge.* D. J. BAKER AND D. H. TOMBOULIAN, *Cornell University.*—The available experimental data[1,2] on the absorption coefficient of Be for photon energies above and below the *K* absorption edge (112 ev) are compared with predictions from theory.[3] Plots of the logarithm of the mass absorption coefficient as a function of the logarithm of the wavelength of the incident photon result in straight lines whose slope is 2.40. The "*K*-absorption jump" (the ratio of the absorption coefficient just above and just below the *K* edge) is found to be 6.8. These results are in fair agreement with the corresponding quantities expected from the theory of photoelectric absorption involving *K* shell electrons.

* Supported by the Office by the Office of Naval Research.
[1] L. C. Andrews, Phys. Rev. **54**, 994 (1938).
[2] R. W. Johnston and D. H. Tomboulian, Phys. Rev. **94**, 1585 (1954).
[3] H. A. Bethe and E. E. Salpeter, *Quantum Mechanics of One-and-Two-Electron Systems* (Academic Press, Inc., New York, 1957), p. 303.

JA5. Low Energy X-Ray Mass-Attenuation Coefficients. ALAN J. BEARDEN, *Cornell University,* AND P. R. WISE, *The Johns Hopkins University.*—The attenuation of x rays with energies from 853 to 2991 ev by Al and Mylar films, and C_2H_4, N_2, O_2, Ne, and A gases, has been measured using a high-resolution beryl monochromator. Experimental determinations of the mass-attenuation coefficients with less than 2% probable error have been obtained by low kilovoltage operation of the x-ray tube and by flow-proportional counter detection with pulse-height discrimination. Some features of flow proportional counting using He-A-CH_4 gas will be discussed. A comparision of this work with previous determinations of a few experimental values in this x-ray energy region[1] and a discussion of theoretical predictions for photoelectric cross section will be presented.

[1] C. L. Andrews, Phys. Rev. **54**, 994 (1938).

JA6. Theory of Conformal Solutions Applied to Liquid Alkali Nitrate Mixtures. J. L. KATZ, *University of Chicago,* HOWARD REISS, *Atomics International,* AND O. J. KLEPPA, *University of Chicago.*—Kleppa and Hersh[1] have found that the molar enthalpy of mixing for equimolar liquid alkali nitrate mixtures may be represented by the approximate expression, $\Delta H_m = (U/4)[(d_1-d_2)/(d_1+d_2)]^2$, where U is the lattice energy of the mixture and d_1 and d_2 are the interionic distances characteristic of the two pure salts. We have derived an expression similar to this by applying a suitable modification of Longuet-Higgins' theory of conformal solutions.[2] Our results and those of H. Reiss and S. W. Mayer[3] seem to indicate that the lack of success of first-order conformal solution theory may have been due to its application to mixtures of substances whose intermolecular potentials were not really conformal.

[1] O. J. Kleppa and L. S. Hersh, J. Chem. Phys. (to be published).
[2] H. C. Longuet-Higgins, Proc. Roy. Soc. (London) **A205**, 247 (1951).
[3] H. Reiss and S. W. Mayer (to be published).

JA7. Mean Square Length of Isotactic Poly-α-Olefins.* PAUL M. PARKER, VICTOR E. MEYER, AND JACK B. KINSINGER, *Michigan State University.*—The mean square end-to-end length of long isotactic vinylic hydrocarbon-type chains (poly-α-olefins) has been calculated by treating the problem as a Markov process in the manner of Tobolsky.[1] The problem of excluded volume is ignored. An outline of the calculation and the result will be presented and discussed.

* Work supported in part by a grant from the Research Corporation and in part by a National Science Foundation Summer Fellowship.
[1] A. V. Tobolsky, J. Chem. Phys. **31**, 387 (1959).

JA8. Flame Propagation in Free Radical Containing Solids at Low Temperatures. A. L. BERLAD, *Convair Scientific Research Laboratory.*—A theory of flame propagation in free radical containing inert matrices is formulated. Although the general theoretical formulation is nonadiabatic, the near-adiabatic approximation may be employed, in conjunction with experimentally determined flame propagation velocities, to deduce the activation energy E for the jump of an interstitial free radical in an inert solid matrix. The spatial temperature and composition profiles associated with the given near-adiabatic flame are deduced simultaneously. The *complete* nonadiabatic formulation is *necessary,* however, to a deduction of existence limits for flame propagation. This is demonstrated. Application of the formulation is illustrated for the case of flame propagation in N atom containing solid N_2. For this case, an experimentally determined burning velocity of 2 cm/sec is used to deduce a value of $EW1$ kcal/mole, as well as the associated temperature and composition profiles.

JA9. "Sectio Aurea" in the Composition of Crystalline Matter. NICHOLAS EFREMOV.—If we assume the concept of harmonical mass relations of chemical elements in the structure of crystals, we can precalculate the chemical formulas of some rockforming minerals and that of silicates in particular. This precalculation is based on the rule of "sectio aurea" (series of relations 2:3, 3:5, 5:8, or 3:5:8, etc.) which characterizes the relations between two or three components (Me-metal, Si, O) constituting the chemical composition of rockforming silicates. The empirical data are in good agreement with this theoretical precalculation:

Silicates	Mass relations
Forsterite—Mg_2SiO_4	$Si:Mg_2:O_4 = 3:5:7$
Anorthite—$CaAl_2Si_2O_8$	$Si_2:CaAl_2:O_8 = 3:5:7$
Albite —$NaAlSi_3O_8$	$NaAl:Si_3:O_8 = 3:5:8$

The same rule explains for the first time the so-called "anomalies" in the chemical composition of iron monosulfides, as pyrrhotite, etc. The formula of the most abundant pyrrhotite is not FeS (as usually given in manuals), but Fe_6S_7, Fe_9S_8, etc., where mass relations $S:Fe = 2:3$. Not only the composition of rockforming silicates, but also that of some igneous and metamorphic rocks constituting the earth's crust, follow the same rule.

JA10. Adsorption of Air and Oxygen by Evaporated Films of Titanium and Zirconium. E. J. ZDANUK AND S. P. WOLSKY, *Raytheon Company* (introduced by W. C. Dunlap).—The Wagener calibrated capillary flow technique was used to study the adsorption of air and oxygen by evaporated films of titanium and zirconium at room temperature. By the use of a premelting and outgassing filament shield the films on the walls of the reaction flask were formed at dynamic ambient pressures of 10^{-8} mm Hg or less. The Bayard-Alpert type ionization gauges used in this apparatus had LaB_6 coated filaments. This modification permitted low filament temperature operations thus minimizing the effect of thermal gaseous reactions. A glass plate with evaporated gold electrodes in the reaction flask was used to measure the electrical resistance of the metal film as a function of its thickness. The resistances also were sensitive to adsorption and desorption processes occurring in the reaction flask. The adsorption rates were measured in the pressure range of 10^{-4} to 10^{-8} mm Hg.

JA11. Theory of the Surface Tension of Fused Salts.* HOWARD REISS AND S. W. MAYER, *Atomics International.*—A theory of the surface tension of fused salts is presented based on the Reiss, Frisch, Helfand, and Lebowitz[1] theory of liquids, modified by the theory of conformal solutions due to Longuet-Higgins.[2] The theory allows one to compute the surface tension of a fused salt knowing only the temperature, the density, and the diameters of the ionic hard cores. It has been applied to

uni-univalent, uni-divalent, and uni-trivalent salts. Agreement with experiment is very good. The mercuric salts, known to be un-ionized, yield anomalous results. This is expected on the basis of the theory and indicates that it may be useful in structural investigations.

* Work performed under contract to the U. S. Atomic Energy Commission.
[1] H. R. Reiss, H. L. Frisch, E. Helfand, and J. L. Lebowitz, J. Chem. Phys. **32**, 119 (1960).
[2] H. C. Longuet-Higgins, Proc. Roy. Soc. (London) **A205**, 247 (1951).

JA12. Correlation in the Diffusion of Hydrogen in Hydrides.* G. G. LIBOWITZ AND HOWARD REISS, *Atomics International*.—The metal hydrides are excellent systems for the study[1] of the vacancy mechanism of diffusion because the vacancy concentration can be controlled at one temperature by fixing the composition of the hydride. They are even more suitable for the study of correlation effects[2] in diffusion. To this end we have calculated the correlation factors for the diffusion of hydrogen and deuterium in the tetrahedral or octahedral sites of typical hydrides. Hydrogen diffusing in deuteride is also considered. Diffusion studies involving correlation also should yield information on the clustering or ordering of vacancies in these substances.

* Work performed under contract to the U. S. Atomic Energy Commission.
[1] B. Stalinski, C. K. Coogan, and H. S. Gutowsky, J. Chem. Phys. **33**, 933(L) (1960).
[2] J. Bardeen and C. Herring, *Imperfections in Nearly Perfect Crystals* (John Wiley & Sons, Inc., New York, 1952), p. 261.

THURSDAY MORNING AT 9:45

New Yorker, Terrace Room

(E. P. WIGNER presiding)

Symposium on General Relativity

K1. Curved Empty Space-Time as the Building Material of the Physical World: an Assessment. J. A. WHEELER, *Princeton University*. (30 min.)

K2. Observables in General Relativity. P. G. BERGMANN, *Syracuse University*. (30 min.)

K3. Convergence Problems in Quantizing Gravitation as a Spin-Two Meson Field. R. P. FEYNMAN, *Carnegie Institute of Technology*. (30 min.)

K4. Cosmological Inferences from Astronomical Observations. THOMAS GOLD, *Cornell University*. (30 min.)

THURSDAY MORNING AT 9:45

Martinique, Empress Josephine Room

(J. D. JACKSON presiding)

Theoretical Physics III: Hyperfragments; Weak Interactions; Many-Body Systems

KA1. Double Hyperfragments and Relative Parity of Λ and Σ Hyperon. SYUREI IWAO,* *Syracuse University* (introduced by R. L. Arnowitt).—In a previous paper[1] a theory of hyperfragments was developed. The parameters of the two-body N-Λ interaction were determined from the observed binding energies of the Λ hyperon. They explained well the present experimental status of hyperfragments. We here apply this method to the so-called "double hyperfragments." The double hyperfragments are bound states of two Λ particles and ordinary nuclei. One might expect such systems could be produced by the absorption of high-energy K^- mesons by complex nuclei or by Ξ^- absorption. One has only one additional parameter in the $^1S_0$ state not previously determined by the single hyperfragment analysis. With the use of global symmetry one expects that double hyperfragments should exist for $A \gtrsim 4$. The binding energies of the double hyperfragments are of interest because the sign of the $^1S_0$ potential for the Λ-Λ interaction is closely related to the relative parity of the Λ and Σ particles. Thus the two-pion exchange potential gives an attractive force here for the same parity while zero for opposite parity. For opposite parity bound states will form for $A \gtrsim 5$.

* Supported in part by the National Science Foundation and the U. S. Air Force Office of Scientific Research.
[1] S. Iwao and E. C. G. Sudarshan, Phys. Rev. Letters **4**, 140 (1960).

KA2. Analysis of the Light Λ-Hypernuclear Systems. K. DIETRICH,* R. FOLK,† AND H. J. MANG, *Institut fuer Theoretische Physik, Heidelberg*.—The ground-state energy of the systems consisting of a lambda particle bound to two, three, and four nucleons is computed from elementary two-particle potentials. Both the nucleon-nucleon and the Λ-nucleon interactions are assumed to be spin dependent, central potentials with square well shapes outside of a hard core. The ground-state energy is computed as a function of the parameters of the Λ-nucleon interaction. A method first introduced by J. Brenig[1] for many fermion problems is adapted to these hyperfragment systems and consists essentially of solving the two-particle problem for each pair in an "average field" of the remaining particles. This "average field" is chosen in a self-consistent calculation so as to minimize the "first corrections" to the energy. The accuracy is checked by computing higher order corrections and by computing the energy using three independent approximate expressions.

* Now at Institut fuer Theoretische Physik, Frankfurt.
† Now at Princeton University, Princeton, New Jersey.
[1] J. Brenig, Nuclear Phys. **4**, 363 (1957).

KA3. Muon Capture in He^3. LINCOLN WOLFENSTEIN, *Carnegie Institute of Technology*.—The rate Λ of the muon capture reaction $\mu^- + He^3 \rightarrow H^3 + \nu$ is of great interest because

He^3 is the simplest target for which there are no complications of mesic-molecular formation. The allowed nuclear matrix elements have been calculated[1]; these depend primarily on the mean-square nuclear radius. We have calculated the forbidden nuclear matrix elements previously ignored, in particular, relativistic terms proportional to the proton momentum. In the good approximation that the He^3 wave function is a product of a space function and a spin-isotopic-spin function, these can be calculated exactly and reduce Λ by about 3%. If the *ft* value of H^3 decay is set at 1150, the resulting value of Λ is 1.54×10^3 sec^{-1} with an uncertainty of about 5% depending on the nuclear wave function. A statistical mixture of $F=1$ and $F=0$ hyperfine states of the He^3 mesic atom has been assumed; if some unlikely mechanism were to relax all the atoms to the $F=1$ ground state, the capture rate would be reduced by 10%.

[1] A. Fujii and H. Primakoff, Nuovo cimento 12, 327 (1959); C. Werntz, Nuclear Phys. 16, 59 (1960).

KA4. Intermediate Vector Boson and Radiative Lepton Decay of the *K* Meson.* AKIRA KANAZAWA† AND MASAO SUGAWARA, *Purdue University*, AND KATSUMI TANAKA, *Argonne National Laboratory*.‡—*K*-meson decay into electron, neutrino, and photon is analyzed in the lowest order perturbation with respect to weak and electromagnetic interactions but without making any approximation regarding the strong interaction. The weak interaction is assumed to be transmitted by a single charged intermediate vector meson which interacts with the weak current in the conventional way. It is pointed out here that a certain angular and momentum distribution of decay particles could reveal almost unequivocally whether the intermediate vector meson does exist. It is shown also that other lepton decays of the K meson which include μ mesons and π mesons cannot be used for the same purpose.

* Work supported in part by the National Science Foundation and the U. S. Atomic Energy Commission.
† On leave of absence from Physics Department, Hokkaido University, Sapporo, Japan.
‡ Temporary address for 1960–1961 is Istituto di Fisica Teorica dell' Universita di Napoli, Mostra dell'Oltremare, Napoli, Italy.

KA5. The ξ Approximation for First-Forbidden β Decay.* R. M. STEFFEN, *Purdue University*.—In order to explain the statistical shape of most non-unique first-forbidden β transitions, the ξ approximation has been introduced by Konopinski and Uhlenbeck.[1] According to this approximation, which presupposes $\xi=\alpha Z/2R\gg W_0$, the anisotropy factor $A_2(W)$ in the β-γ directional correlation $w(\theta)=1+A_2(W)P_2(\cos\theta)$ is proportional to $(1-W^2)/W$, where W is the β energy in units of mc^2.[2,3] The anisotropy factor $A_2(W)$ of three β-γ cascades of widely different Z has been measured as a function of the β energy. The β emitters chosen were K^{42}, Sb^{122}, and Au^{198}. The results on the latter two β transitions agree very well with the predicted energy dependence of $A_2(W)$, whereas a slight deviation from the $A_2(W)=(1-W^2)/W$ law was observed in the case of K^{42}. The deviation in the case of K^{42} is not unexpected since ξ is of the same order of magnitude as W_0. Upper limits for the B_{ij} contribution to the β transitions of the three nuclei may be assigned on the basis of the modified B_{ij} approximation.[3]

* Work supported by the U. S. Atomic Energy Commission.
[1] E. J. Konopinski and G. E. Uhlenbeck, Phys. Rev. 60, 308 (1941).
[2] T. Kotani and M. Ross, Phys. Rev. 113, 622 (1959).
[3] T. Kotani, Phys. Rev. 114, 795 (1959).

KA6. A Pseudoscalar Interaction as the Origin of Anomalous Beta Decay Spectrum Shapes. J. M. PEARSON, *Université de Montréal*.—The anomalous $(1+b/W)$ factor found by the Langer[1] group in the shapes of many allowed and unique forbidden decays cannot be explained by Fierz interference, electron screening effects, contributions from higher degrees of forbiddenness, or by a conserved vector current. Here we attempt an interpretation in terms of a pseudoscalar interaction in nuclear beta decay, handling the problem of the non-relativistic limit of the Hamiltonian of the pseudoscalar interaction by considering the gradients of both the lepton covariant and the nuclear potential. With a minimum of uncertainty arising from the nuclear matrix elements we require $g_p/Mg_A=-0.1$, which value is shown to be consistent with the $O^-\rightarrow O^+$ Pr^{141} data and is not in disagreement with the theory of the induced pseudoscalar interaction if a strong dependence on momentum transfer is assumed. Now, if we accept that all allowed transitions, except the pure Fermi, must have their spectrum shapes distorted by the pseudoscalar interaction, it follows that the ratio $X=|g_A/g_V|$, deduced from the *ft* values of n and O^{14}, must be re-evaluated, and there is a possibility now that $X=1$.

[1] J. H. Hamilton, L. M. Langer, and W. G. Smith, Phys. Rev. 119, 772 (1960) and references cited therein.

KA7. Gauge Symmetries of Weak and Electromagnetic Interactions. SHELDON LEE GLASHOW, *California Institute of Technology*.—We assume that there exists an extended group of gauge transformations which leave invariant all interactions of elementary particles characterized by dimensionless coupling constants (masses or mass-producing interactions need not possess the extended gauge symmetry). For each generator of this group there is a corresponding vector boson coupled to a partially conserved current. The photon is included among these vector bosons; the remaining ones are identified as intermediaries of decay interactions. Thus the strong interactions are invariant under parity- and strangeness-violating gauge transformations. One admissable variety of strong interaction is discussed. A four-parameter gauge group suffices to reproduce the known electromagnetic and weak interactions of leptons, but apparently cannot yield weak couplings of baryons compatible with the $\Delta I=\frac{1}{2}$ rule. A six-parameter group (hence six vector bosons) can describe all electrodynamic and weak phenomena. A relationship among the μ-decay, Λ-β-decay, and N-β-decay coupling strengths emerges, and a pseudoscalar $\Delta S=2$ weak interaction (which does not generate a large $K^{(1)}$, $K^{(2)}$ mass splitting) is predicted.

KA8. Spectrum of Decay Electrons from a Mu Mesic Atom. I. HAUSER AND R. J. MALHIOT, *Illinois Institute of Technology*.—A numerical program has been developed for the spectrum of the decay electrons from a mu mesic atom when $Z\gtrsim20$. Finite nuclear size and the effect of the nuclear electric field on the emitted electron wave function are taken accurately into account. The key idea is to use an expansion of the final electron state in spherical waves; only the first few terms of the expansion are required since $pR<6\hbar$ where p is the maximum momentum of the emitted electrons and R is the Bohr radius of the mu meson for $Z\gtrsim20$. The numerical program and partial results for $Z=20$ and $Z=26$ will be discussed.

KA9. Dirac Wave Functions of a Decay Electron from a Mu Mesic Atom. R. J. MALHIOT AND I. HAUSER, *Illinois Institute of Technology*.—For ranges of energy involved in the decay of mu mesons, a numerical program has been developed for computing Dirac wave functions of an electron in a Coulomb field modified by finite nuclear size. A new asymptotic series, which is useful for normalizing the wave function in the continuum, has been found. The program and the method of normalization will be discussed.

KA10. Nuclear Many-Body Theory in the Boundary Condition Representation. M. MCMILLAN AND E. LOMON, *Massachusetts Institute of Technology*.—The boundary condition representation for nuclear forces previously has been shown to lead to a soluble equation for the nuclear reaction matrix for pair center-of-mass momentum $P=0$.[1] The representation reduces to a system of coupled algebraic equations for the case of $P\neq0$, including tensor coupling. The number of coupled functions is infinite but a truncated system is a good approximation for small P. The lowest order truncation already corresponds to

the usual averaging over angles in the operator which projects out of the Fermi sea. Higher order calculations are quite feasible. The effect of $P \neq 0$ on the presence of a "gap" will be discussed. The effect of the hole-hole interaction on the pairing gap will be discussed in conjunction with the effect of the single-particle gap proposed by Thouless.[2]

[1] E. Lomon, Bull. Am. Phys. Soc. Ser. II, 3, 183 (1958).
[2] D. J. Thouless, Phys. Rev. 112, 906 (1958).

KA11. Phase Shifts for a Velocity-Dependent Potential.* M. RAZAVY, *Louisiana State University* (introduced by J. S. Levinger).—We previously[1] calculated nucleon-nucleon phase shifts, assuming a nonsingular, velocity-dependent potential of the form $-V_0J_1(r)-(\lambda/M)\mathbf{p}\cdot J_2(r)\mathbf{p}$. The choice $J_1=J_2$ = square well gave a fair fit to ^1S data but did not fit ^1D values. We now choose: $J_1=J_2=1 (r<1f)$; $J_2=0 (r>1f)$; $J_1=10\exp(-2r)[1+1.2\exp(-2r)]^{-2}$, $(r>1f)$; $V_0=40$ Mev; $\lambda=-2.23$. If we neglect Coulomb forces, we solve analytically for ^1S phase shifts. Calculated values agree with effective range parameters ($r_0=2.5f$, $a=-15.5f$) at low energy and agree with Breit's values[2] to within 0.02 radian from 20 to 340 Mev. ^1D phase shifts K_2 calculated with Born approximation are compared below with Breit's *YLAM*.

E (Mev)	83	187	269	332
Our K_2 (radians)	0.047	0.092	0.096	0.072
Breit's *YLAM*	0.06	0.12	0.16	0.18

* Supported by the National Science Foundation.
[1] M. Razavy and J. S. Levinger, Bull. Am. Phys. Soc. Ser. II, 5, 441 (1960).
[2] Breit, Hull, Lassila, and Pyatt, preprint "Phase-parameter representation of proton-proton scattering from 9.7 to 345 Mev."

KA12. Perturbation Treatment of a Neutron Gas.* J. S. LEVINGER, *Louisiana State University*.—I have used perturbation theory to find the energy/particle (E/N) to first order for a neutron gas, assuming well-behaved velocity-dependent neutron-neutron potentials: v_1 = Razavy's (preceding abstract) and v_2 = square-wells[1] for both static and velocity-dependent terms. To facilitate comparison with E/N found by Brueckner *et al.*[2] by a different method for the Gammel-Thaler potential, I assume that the static terms have a weak central attraction (10% of singlet-even) in triplet-odd states and that the velocity-dependent terms have Wigner character. For Fermi wave numbers from 0.64 to $1.0f^{-1}$, v_1, v_2, and Brueckner *et al.* agree to within $\frac{1}{2}$ Mev. There is increasing disagreement at higher densities. Second-order energy $E^{(2)}$ is estimated $-1<E^{(2)}<0$. These results for E/N support Bég's argument[3] that different potentials equivalent in the two-body problem are nearly equivalent in the many-body problem.

* Supported by the National Science Foundation.
[1] M. Razavy and J. S. Levinger, Bull. Am. Phys. Soc. Ser. II, 5, 441 (1960).
[2] K. A. Brueckner, J. L. Gammel, and J. T. Kubis, Phys. Rev. 118, 1095 (1960).
[3] See R. E. Peierls, *Proceedings of the International Conference on Nuclear Structure* (University of Toronto Press, Toronto, 1960), p. 7.

KA13. Fermi-Surface Discontinuity and Single-Particle Renormalization Constant for an Electron Gas.* P. FULDE, *University of Maryland* (introduced by R. A. Ferrell).—According to Migdal's theorem[1] the magnitude of the discontinuity in the momentum distribution of an interacting degenerate electron gas is equal to the single-particle renormalization constant. The latter has been calculated from the study of the self-energy of a single-electron excitation.[2] In a similar fashion, the Green's function method also can be applied to the calculation of the entire momentum distribution. The results for the momentum distribution can be compared with those of Daniel and Vosko[3] and of Goldstone[3] obtained by a different method. As a check on the results for the momentum distribution, the total kinetic energy can be calculated. From this, by means of the Virial theorem, the actual ground-state energy can be obtained and compared with the direct calculation by Gell-Mann and Brueckner.

* Investigation supported by the U. S. Air Force Office of Research and Development.
[1] A. B. Migdal, Soviet Phys.—JETP 5, 333 (1957).
[2] J. J. Quinn and R. A. Ferrell, Phys. Rev. 112, 812 (1958).
[3] E. Daniel and S. H. Vosko, Phys. Rev. 120, 2041 (1960); J. Goldstone (unpublished).

THURSDAY MORNING AT 9:45

New Yorker, Grand Ballroom

(H. A. BETHE presiding)

Invited Papers in Nuclear Physics

L1. Studies of the Solid State with Recoil-Free Photons. R. L. MÖSSBAUER, *California Institute of Technology*. (40 min.)

L2. Electron Scattering by Protons. R. R. WILSON, *Cornell University*. (40 min.)

L3. Progress in High Magnetic Field Research. H. P. FURTH, *Lawrence Radiation Laboratory, Livermore*. (40 min.)

THURSDAY AFTERNOON AT 2:00

Manhattan Center

Joint Ceremonial Session of APS and AAPT

(FREDERICK SEITZ presiding)

Retiring Presidential Address of The American Physical Society

LA1. Problems of Nuclear Structure. V. F. WEISSKOPF, *Massachusetts Institute of Technology and CERN*.

(LEONARD OLSEN presiding)

LA2. Presentation of the Oersted Medal of the AAPT. F. W. SEARS.
LA3. Response of the Oersted Medallist. J. R. ZACHARIAS.

Twentieth Richtmyer Memorial Lecture of the AAPT

LA4. Deuteronomy: The Synthesis of Deuterons and the Light Nuclei during the Early History of the Solar System. W. A. FOWLER, *California Institute of Technology.*

FRIDAY MORNING AT 9:45

New Yorker, Grand Ballroom

(L. M. BRANSCOMB presiding)

Symposium of the Division of Electron Physics

M1. Electron Attachment and Detachment in Molecular Oxygen. A. V. PHELPS, *Westinghouse Research Laboratories.* (40 min.)
M2. Free-Particle Cyclotron Resonance and the Determination of Atomic Constants. PETER FRANKEN, *University of Michigan.* (40 min.)
M3. Experimental Studies of Ion Resonance in a Multicomponent Plasma. S. J. BUCHSBAUM, *Bell Telephone Laboratories.* (40 min.)

Business Meeting of the Division of Electron Physics

(to be held at whatever time the Chairman chooses)

FRIDAY MORNING AT 9:30

Statler-Hilton, Terrace Ballroom West

(S. DEVONS presiding)

Nuclear Reactions II

MA1. Ranges and Energy Loss of Tritons in Various Substances. W. N. BISHOP,* R. L. WOLKE,† E. EICHLER, NOAH R. JOHNSON, AND G. D. O'KELLEY, *Oak Ridge National Laboratory.*‡—The following ranges of 2.736-Mev tritons have been measured: aluminum, 10.10 mg/cm²; nickel, 15.15 mg/cm²; polystyrene, 6.12 mg/cm²; nitrogen, 7.26 mg/cm²; argon, 11.40 mg/cm²; krypton, 17.83 mg/cm²; xenon, 20.36 mg/cm²; air 7.34 mg/cm². Values of energy loss were determined between 0.2–2.7 Mev. The tritons were produced by the reaction $Li^6(n,\alpha)H^3$ using a reactor neutron beam. A silicon surface barrier detector and multi-channel pulse height analyzer were used to measure the triton energy as a function of absorber thickness. Background effects were eliminated by demanding a coincidence between the tritons and accompanying alpha particles (correlated at 180°), which were detected in a second surface barrier detector. From these data, range and energy loss curves were constructed and empirical range-energy relations generated.

*ORINS Graduate Fellow from University of Florida, Gainesville, Florida.
† Permanent address: University of Pittsburgh, Pittsburgh, Pennsylvania.
‡ Operated by Union Carbide Corporation for the U. S. Atomic Energy Commission.

MA2. Tritium Induced Reactions in Light Nuclei. H. D. HOLMGREN AND L. M. CAMERON, *U. S. Naval Research Laboratory.*—The differential cross sections as functions of angle and bombarding energy for a number of (t,p), (t,d), and (t,α) reactions on various light nuclei have been studied in the bombarding energy region from about 1 to 2 Mev. The purpose of these investigations has been to study the systematic behavior of these reactions and to compare them with earlier He^3 studies. The studies of tritium induced reactions on B^{10}, C^{13}, and O^{16} have been presented in previous papers.[1] Recent studies have extended the observations on B^{10} to additional α-particle and deuteron groups. Also the (t,α) reactions have been studied using Li^6, Li^7, and B^{11} targets. The magnitudes of the cross sections were observed to vary by more than a factor of 100, and the behavior of the angular distributions were observed to change drastically from one reaction to another. Some of the yield curves exhibit resonances; however, they are usually rather weak. The nature of the reactions appears to depend rather strongly on the structure of the particular initial and final nuclei involved. The cluster model of nuclear structure seems to be particularly successful in accounting for many features of these reactions.

[1] H. D. Holmgren, R. L. Johnston, and E. A. Wolicki, Bull. Am. Phys. Soc. Ser. II, 4, 403 (1959); G. D. Gutsche, H. D. Holmgren, and R. L. Johnston, *ibid.* 4, 321 (1959); R. L. Johnston, H. D. Holmgren, and G. D. Gutsche, *ibid.* 4, 403 (1959).

MA3. Energy and Angular Correlations in the $N^{14}(p,2p)$ Reaction at 19 Mev.* ROBERT W. DETENBECK,† *Princeton University.*—The $N^{14}(p,2p)$ reaction leading to the ground

state of C^{13} was initiated by 19-Mev protons from the Princeton cyclotron. The emergent protons were detected in coincidence. Energy spectra were recorded on the Princeton two-dimensional pulse-height analyzer.[1] For every angle at which measurements were made the energy spectrum of the protons showed two strong peaks. Dependence of the peak energies on detector angles and incident beam energy was characteristic of the two-step reaction process $N^{14}(p,p')N^{14*}(p'')C^{13}$. The strong angular correlation between the inelastic and decay protons, as well as the selection of one state (or group) in N^{14*} at 11.4 Mev, suggests a direct interaction mechanism. The angular correlations are not well fitted by a simple Satchler model.[2]

* Supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.
† Now at the University of Maryland. During part of this work the author was a General Electric Predoctoral Fellow at Princeton.
[1] M. Birk, T. H. Braid, and R. W. Detenbeck, Rev. Sci. Instr. 29, 203 (1958).
[2] G. R. Satchler, Proc. Phys. Soc. (London) A68, 1037 (1956).

MA4. Proton Capture into a High-Spin State of N^{14}.* JAMES C. ARMSTRONG, JERRY B. MARION, ROBERT W. DETENBECK, AND WILLIAM F. HORNYAK, *University of Maryland.*—Careful measurements of a slight anomaly in the $C^{13}(p,\gamma)$ excitation curve near 1 Mev revealed the presence of a weakly excited, narrow level in N^{14} at an excitation energy of 8.49 Mev. Presumably this is the level seen by Miller *et al.*[1] in the $N^{14}(\alpha,\alpha')N^{14*}$ reaction. Warburton and Pinkston[2] suggest the level as a candidate for one of the $T=0$, $J^\pi=3^+$ or 4^+ levels of $(p_{1/2},f_{7/2})$. The thick-target yield corresponds to the small value of 0.01 ev for the quantity $(\Gamma_p\Gamma_\gamma/\Gamma)\times$(statistical factors). For the nearby level at 8.62 Mev this quantity is 1.3 ev.[3] Because the new level rides on the low-energy tail of the 8.62- and 8.71-Mev levels, the gamma-ray spectrum is difficult to disentangle. Measurements of the gamma-ray decay modes of the 8.49-Mev level and their pertinence to the shell-model description of the state will be discussed.

* Supported in part by the U. S. Atomic Energy Commission.
[1] D. W. Miller, B. M. Carmichael, U. C. Gupta, V. K. Rasmussen, and M. B. Sampson, Phys. Rev. 101, 740 (1956).
[2] E. K. Warburton and W. T. Pinkston, Phys. Rev. 118, 733 (1960).
[3] F. Ajzenberg-Selove and T. Lauritsen, Nuclear Phys. 11, 168 (1959).

MA5. Absolute Differential Cross Sections for $C^{13}(d,n)N^{14}$ and $O^{18}(d,n)F^{19*}$ (2.78-Mev Level).* R. E. BENENSON† AND B. YARAMIS, *Columbia University.*—The absolute differential cross sections for neutrons from the $C^{13}(d,n)N^{14}$ reaction which leave N^{14} in its ground, 2.31-, 3.95-, and 4.9-Mev levels and for neutrons from the $O^{18}(d,n)F^{19}$ reaction which leave F^{19} in its 2.78-Mev level have been obtained using a gas-recoil fast neutron spectrometer and enriched gas targets. $\bar{E}_d=3.9$ Mev. Part of the present $C^{13}(d,n)N^{14}$ work was to check a previous thin target ground state angular distribution[1] unlike the correct $l_p=1$ distribution obtained with a thick target.[2] The present work now yields very similar $l_p=1$ distributions for the lowest three states in N^{14} with the following c.m. differential cross sections in mb/sr at peak: 5.5 ± 0.7, 2.6 ± 0.3, 6.9 ± 0.8. The $l_p=0$ (4.9-Mev level) distribution yields a value of 33.4 mb/sr with some unresolved counts from the 5.1-Mev level. Reduced widths will be extracted. The F^{19} 2.78-Mev neutron group angular distribution decreased smoothly from 0° to 90° and then showed a slight rise. This pattern is inconsistent with spin-flip stripping being important to this $J=7/2$ or $9/2$ level.[3]

* This work partially supported by the U. S. Atomic Energy Commission.
† Permanent address: College of the City of New York.
[1] R. E. Benenson, Phys. Rev. 90, 420 (1953).
[2] D. A. Bromley and L. Goldman, Phys. Rev. 86, 790 (1952).
[3] J. E. Bowcock, Phys. Rev. 112, 923 (1958).

MA6. $O^{16}(d,n)F^{17}$ Reaction. E. W. HAMBURGER, O. DIETZSCH, AND F. C. ZAWISLAK, *Universidade de São Paulo.*—Angular distributions for this reaction have been obtained at six energies between the threshold (1.83 Mev) and 2.4 Mev. Deuterons accelerated by the University of São Paulo electrostatic generator bombarded a tungsten oxide target located 3 m above the floor. In the energy range covered, only one neutron group exists, corresponding to the F^{17} g.s. A conventional long counter therefore could be used to detect the neutrons. Background was measured by bombarding a tungsten blank. The data were corrected for the variation of the counter efficiency with energy and for absorption and scattering of neutrons in the target chamber walls. The angular distributions in the center-of-mass system are approximately isotropic near threshold. As the energy is raised, the cross section in the backward directions increases faster than at forward angles; at ~100 kev above threshold the cross section at 120° is 1.5 times the cross section at 0°. At higher energies the anisotropy increases, and the maximum in the cross section moves from ~120° to ~70°. At 2.33 Mev the cross section at 70° is 4 times the 0° cross section and twice the 160° cross section. The results will be discussed in terms of direct reaction theories.

MA7. Resonance Scattering of Bremsstrahlung by F^{19}, Al^{27}, Si^{28}, and S^{32}.* E. C. BOOTH, *Boston University,* AND K. A. WRIGHT, *MIT.*—Lifetimes of nuclear states were deduced from the intensity of fluorescence radiation emitted under Bremsstrahlung excitation from a Van de Graaff electron accelerator. In cases of high isotopic abundance with Z less than 50, lifetimes of the order $10^{-12}E^{-2}$ g sec can be measured for 0.5 Mev$<E<$2.5 Mev with an accuracy of about 50%. The following mean lifetimes were obtained: B^{11}, 2.34 Mev, $\tau=7\times10^{-15}$ sec $(4.7\pm0.6\times10^{-15})$[1]; Al^{27}, 2.21 Mev, $\tau=3.5\times10^{-14}$ g sec $(2.7\times10^{-14}$ g)[2]; S^{32}, 2.34 Mev, $\tau=4\times10^{-13}$ sec (1.6×10^{13}),[3] Si^{28}, 1.78 Mev, $\tau=1.3\times10^{-13}$ (6×10^{-13})[3]; F^{17}, 1.46 Mev, $\tau=2.5\times10^{-13}$ g, where previous measurements are shown in parentheses. If the previous B^{11} and Al^{27} measurements[1,2] are used as a calibration, the previous Si^{28} and S^{32} lifetimes[3] obtained by electron scattering are too low by factors of 1.4 and 1.8, respectively.

* Supported by the National Science Foundation.
[1] F. Metzger, C. Swann, and V. Rasmussen, Phys. Rev. 110, 906 (1958).
[2] F. Metzger, C. Swann, and V. Rasmussen, Bull. Am. Phys. Soc. Ser. II, 5, 247 (1960).
[3] R. C. Helm, Phys. Rev. 104, 1466 (1956).

MA8. The 4.25- and 4.97-Mev Levels in Ne^{20}. C. BROUDE AND H. E. GOVE, *Chalk River Laboratories.*—The spin of the 4.25-Mev level in Ne^{20} has been measured as 4 and the spin and parity of that at 4.97 Mev as 2+. In the latter case a previous tentative assignment is confirmed.[1] In both cases no direct ground-state transition is observed. The $E2$-$M1$ amplitude mixture of the transition between the 4.97-Mev level and the first excited state at 1.635 Mev is 0.08 ± 0.02. The reaction employed was $Ne^{20}(pp'\gamma\gamma)$ using protons of energy up to 8 Mev from the Chalk River tandem accelerator and the technique involved measuring $(\gamma\gamma)$ coincidence correlations.[2] The level at 4.97 Mev in Ne^{20} is of importance in nucleogenesis because of the role it could play in helium thermonuclear reactions.[3] The present 2+ assignment allows such stellar reactions to produce substantial amounts of Ne^{20} if the reduced alpha-particle width of the level is 1% of the single particle limit[4] or greater.

[1] H. E. Gove, A. E. Litherland, and A. J. Ferguson, Bull. Am. Phys. Soc. Ser. II, 3, 36 (1958).
[2] C. Broude and H. E. Gove, *Proceedings of the International Conference on Nuclear Structure,* edited by Bromley and Vogt (University of Toronto Press, Toronto).
[3] E. E. Salpeter, Phys. Rev. 107, 516 (1957).
[4] A. G. W. Cameron, Chalk River Rept. CRL-41 (AECL No. 454), June, 1957 (unpublished).

MA9. Angular Correlations in Inelastic Proton Scattering from Mg^{24}.* T. H. BRAID, J. L. YNTEMA, AND B. ZEIDMAN, *Argonne National Laboratory.*—Protons of 10.8-Mev energy have been scattered from a natural magnesium target, and the angular distribution of the inelastic group corresponding to the 1.39-Mev first excited state of Mg^{24} has been measured. For this group, the yield at 90° to the beam direction shows little variation with energy. Angular correlations between

these inelastic protons and the de-exciting γ ray have been measured for $\theta_p = 30°$, 60°, 90°, 120°, and 150°. For the three forward angles the correlation is predominantly of the form $A + B \sin^2(\theta - \theta_0)$, where θ_0 differs from the classical recoil direction by only a few degrees in the worst case. This suggests that a direct interaction mechanism is predominant. An additional smaller $\sin^2\theta$ term may indicate some spin flip of the scattered proton. At the two backward angles there is no association with the recoil direction and no indication of direct interaction. Least-squares determinations of the parameters of the correlations are being made and will be discussed in terms of the predictions of the plane-wave, distorted-wave, and adiabatic-inelastic-scattering models.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

MA10. Energy Levels of Mg^{26} from the Decay of Long-Lived Al^{26}.* P. S. JASTRAM, W. L. SKEEL, AND M. K. RAMASWAMY, *The Ohio State University.*—The low-lying energy levels of Mg^{26} are of interest since Mg^{24} is known to have a rotational spectrum and Mg^{26} probably lies in a region of transition toward a vibrational type of spectrum. The decay of long-lived Al^{26} to Mg^{26} has been studied using scintillation counters. A careful analysis of the gamma-spectrum has confirmed the presence of gamma rays of 1.12, 1.85, and 2.95 Mev reported by Ferguson.[1] No other gamma rays were observed. We have measured the ratio of electron capture to positron emission to the 1.85-Mev level; the result, approximately 0.12, is not inconsistent with the interpretation from spectral shape measurements[1] that the beta transition is unique second-forbidden ($\Delta J = 3$, no). An angular correlation measurement of the 1.85- to 1.12-Mev gamma cascade is being attempted. The current coincidence rate is 12 counts per day.

* Supported by the U. S. Atomic Energy Commission.
[1] J. M. Ferguson, Bull. Am. Phys. Soc. Ser. II, 2, 395 (1957).

MA11. Distorted Wave Analysis of the Reaction $Si^{28}(d,p)Si^{29}$. B. BUCK AND G. R. SATCHLER, *Oak Ridge National Laboratory.*—The distorted wave Born approximation theory has been applied to the Chalk River experimental results[1] on the reaction $Si^{28}(d,p)Si^{29}$ at deuteron energies of 6 to 9 Mev. Protons leading to the ground ($l=0$), 1.28 Mev ($l=2$), and 2.03 Mev ($l=2$) states of the residual nucleus were analyzed. The distorting optical potentials were adjusted to fit the (d,p) angular distributions and were found to give a reasonable description of the elastic scattering of protons from Si and deuterons from Al at comparable energies. The corresponding $(d,p\gamma)$ angular correlation functions for the $l=2$ transitions agree well with the experimental measurements. The proton polarization for these transitions is also predicted. The effects of varying the optical potential parameters will be discussed. The calculations were carried out on the Ferranti "Mercury" at Oxford and the IBM-704 at Oak Ridge.

[1] J. A. Kuehner, E. Almqvist, and D. A. Bromley, Phys. Rev. Letters 4, 132 (1960), and to be published.

MA12. Low-Energy (p,p') Angular Distributions and $(p,p'\gamma)$ Angular Correlation.* H. TAKETANI AND W. PARKER ALFORD, *University of Rochester.*—$(p,p'\gamma)$ angular correlations at the indicated scattering angle have been measured for protons leading to the first excited states in the following nuclei: Si^{28}(45°,90°,135°), S^{32}(90°,135°), Ti^{48}(90°,135°), Ni^{58}(45°, 90°,135°), Ni^{60}(50°,90°,135°). Nearly all measurements were made at proton energies of 5.85 and 6.9 Mev with an energy spread of about 200 kev in the incident beam. For Si^{28}, except at 135°, 5.9 Mev, the correlation is of the form $A + B \sin^2(\theta - \theta_0)$ where θ_0 is close to the direction of the recoil nucleus. The same is true for Ni^{60} at 50°, 135°, and 6.9 Mev. The other measurements are generally consistent with the predictions of the statistical model with indications of a small direct interaction contribution in some cases. Angular distributions of protons to all these states also have been measured at 5.85 and 6.9 Mev. These data also will be presented and discussed in the light of the correlation measurements.

* Supported by the U. S. Atomic Energy Commission.

MA13. New Isotope Al^{30}.* E. L. ROBINSON AND O. E. JOHNSON, *Purdue University.*—In a study of short half-life isotopes, a 3.3-sec activity was produced by bombarding high-purity natural silicon with fast neutrons from the deuteron bombardment of lithium. The decay was studied using scintillation techniques. In addition to the radiations from known isotopes, two gamma rays of 2.2 and 3.5 Mev were observed with a half-life of 3.3 sec. A beta spectrum with the same half-life and a maximum energy of 4.7 Mev also was observed. The assignment of this activity to Al^{30} will be discussed, and features of the proposed decay scheme will be presented.

* Supported in part by U. S. Atomic Energy Commission.

MA14. Excited States of A^{38} from the $Cl^{37}(p,n)A^{37}$ Reaction.* G. S. MANI, A. C. L. BARNARD, T. A. TOMBRELLO, AND D. A. A. S. N. RAO,† *Rice University.*—Approximately 150 levels in A^{38} have been resolved from an investigation of the $Cl^{37}(p,n)A^{37}$ reaction for proton energies between 1.6 Mev and 2.9 Mev. In this energy range the reaction may proceed only to the ground state of A^{37}. A NaCl target 1 kev thick deposited on tungsten was used, and the neutrons were detected with a long counter. The widths of the levels were measured to an accuracy of about 1 kev, and their average spacing was found to be 10 kev. The levels seem to form two distinct groups which may be associated with the giant resonances described by Lane, Wigner, and Thomas. These two groups do not appear as prominently in the $Cl^{37}(p,\alpha)S^{37}$ reaction; this reaction shows far fewer resonances, probably because of the more limited choice of parities. An excitation curve for the (p,n) reaction also has been taken using a 100-kev target. The neutrons corresponding to leaving A^{37} in its ground state and first excited state were detected by the energy-sensitive sphere counters of Bramblett *et al.*[1] The theory of Hauser and Feshbach has been applied to obtain the spin values of these two levels.

* Supported in part by the U. S. Atomic Energy Commission.
† Now at the University of Alberta, Edmonton, Canada.
[1] Bramblett, Ewing, and Bonner, Nuclear Instr. & Methods (to be published).

FRIDAY MORNING AT 9:45

Statler-Hilton, Skytop Room

(MELVIN SCHWARTZ presiding)

Mesons, Strange Particles, Antiprotons

N1. $C^{12}(\pi^-,\pi^-n)C^{11}$ Cross Section at 1.0 Bev.* A. M. POSKANZER, J. B. CUMMING, G. FRIEDLANDER, J. HUDIS, AND S. KAUFMAN, *Brookhaven National Laboratory.*—The C^{11} production rate in a plastic scintillator by 1.0-Bev negative pions has been determined by internal scintillation counting of the 20.4-min beta activity. The pion beam was monitored by a

second plastic scintillator connected to a phototube from which the current was integrated during bomardment. The monitoring device was calibrated in a similar manner to the above measurement against the $C^{12}(p,pn)C^{11}$ reaction[1] with 3-Bev protons, assuming that the relative light outputs caused by protons and pions were proportional to their respective values of dE/dx. The effect of Bev electrons in the pion beam was evaluated by varying the atomic number and thickness of the pion producing target. The effect of muons in the beam was estimated to be about 10%. The effects of secondaries on both the C^{11} production and light output were evaluated and taken into account. A preliminary value of about 18 mb was obtained subject to further tests of the linearity of the monitor. The corresponding (p,pn) cross section at the same momentum is about 30 mb.

* Research performed under the auspices of the U. S. Atomic Energy Commission.
[1] J. B. Cumming, G. Friedlander, and C. E. Swartz, Phys. Rev. 111, 1386 (1958).

N2. π^+-Proton Interactions at 0.9, 1.1, and 1.3 Bev.* J. SANFORD, C. BALTAY, H. COURANT, E. FOWLER, H. KRAYBILL, J. SANDWEISS, D. STONEHILL, AND HORACE TAFT, *Yale University.*—In a recent experiment at the Cosmotron, the Brookhaven National Laboratory 20-in. liquid hydrogen bubble chamber has been used, together with an electrostatically separated π^+ beam to study π^+-proton interactions at pion kinetic energies of 0.9, 1.1, 1.3 Bev. Approximately 7000 photographs were taken at 0.9 and 1.3 Bev and 100 000 at 1.1 Bev. At all energies approximately 90% of the beam consisted of positive pions and the momentum (full) width was ±1%. To date a fraction of these photographs has been scanned for (nonstrange)[1] π^+-p interactions and about 2500 events have been found. The ratios of 4-prong to 2-prong events at 0.9, 1.1, and 1.3 Bev are 10/492, 64/1300, and 60/735, respectively. The elastic and inelastic total cross sections at these energies will be presented as well as further details of the interactions.

* Work supported in part by the U. S. Atomic Energy Commission.
[1] See abstract N5 for an account of π^+ production.

N3. Mean Lifetime of the Neutral Pion. R. G. GLASSER, N. SEEMAN, AND B. STILLER, *U. S. Naval Research Laboratory.*—The mean lifetime of the neutral pion has been obtained from measurements of the mean time-of-flight of monoenergetic pions. 66 K^+ decays via the $K_{\pi 3}$ mode in which the neutral pion then undergoes Dalitz decay ($\pi^0 \rightarrow \gamma + e^+ + e^-$) were used. The mean lifetime obtained is $(2.0 \pm 0.4) \times 10^{-16}$ sec. The distribution of distances between the point at which the K^+ comes to rest and the origin of the electron pair has a mean value of $0.093 \pm 0.016\ \mu$. The error is purely statistical and comes from a maximum likelihood analysis of the data. The standard deviation of measurements on the positions of individual minimum ionization tracks is $0.065\ \mu$. The mean error with which the stopping point of the K^+ can be determined is $0.04\ \mu$. The new, finer-grained Ilford L4 emulsion and the improved statistics represent the principal improvements over the original work of Harris, Orear, and Taylor.[1]

[1] G. Harris, J. Orear, and S. Taylor, Phys. Rev. 106, 327 (1957).

N4. Anomalous Emission of Photons from 3.5-Bev π^--Nucleus Collisions.* D. T. KING, *University of Tennessee.*—The energies of 250 electron pairs have been determined in 600-μ Ilford K5 emulsions which had been exposed to a beam of 10^5 cm^{-2} 3.5 Bev/c negative pions. Energies of the individual pair tracks were determined with statistical error less than 20%. The mean polar angles of the pairs relative to the beam direction also were recorded. A dip angle of less than 5° was required for all pairs measured, and those pairs apparently arising from bremsstrahlung were excluded. The angular distribution of the photons is strongly peaked forward with half-angle 16°, and checks confirm that the intensity from outside the stack is small. The spectrum for pairs lying within 10° to the beam direction is characteristic[1] of the decay of neutral pions with kinetic energies mainly 0–300 Mev and a thin tail out to 3 Bev. Outside 10° the photon spectrum shows very little 70-Mev peak and is attributable either to neutral pions, most of which have energies between 0.5–1.2 Bev, or to some other source.

* Supported by the National Science Foundation.
[1] Carlson, Hooper, and King, Phil. Mag. 41, 701 (1950).

N5. Hyperons from π^+p Interactions.* C. BALTAY, H. COURANT, W. FICKINGER, E. FOWLER, H. KRAYBILL, J. SANDWEISS, J. SANFORD, D. STONEHILL, AND HORACE TAFT, *Yale University.*—The 20-in. liquid hydrogen bubble chamber of the Brookhaven National Laboratory Bubble Chamber Group was exposed to separated π^+ beams of 1300, 1100, and 900 Mev.[1] This paper concerns hyperon production in $\pi^+ + p \rightarrow \Sigma^+ + K^+$ (threshold pion energy = 890 Mev). 7866 stereo-photographs were scanned at 1300 Mev for sigma events, yielding 91 possible sigmas. 100 000 photographs at 1100 Mev have produced approximately 500 sigmas. In addition to the sigmas, one certain and two possible lambdas were found in the 1300-Mev pictures. Total and differential cross sections for sigma production and sigma decay distributions will be presented.

* Work supported in part by the U. S. Atomic Energy Commission.
[1] See abstract N2 of this meeting for a discussion of nonstrange particle interactions.

N6. Photoproduction of K^+ Mesons from Hydrogen.* D. A. EDWARDS, R. L. ANDERSON, F. TURKOT,† AND W. M. WOODWARD, *Cornell University.*—The differential cross section for the production of K^+ mesons in the reaction $\gamma + p \rightarrow K^+ + \Sigma^0$ has been measured at three angles for 1140-Mev photons. The 1200-Mev bremsstrahlung beam from the Cornell synchrotron is passed through a liquid hydrogen target, and K^+ mesons are selected by a magnetic spectrometer. After particles produced at the desired angle and momentum have passed through the spectrometer magnet, K^+ mesons are identified by requiring proper pulse heights in three scintillation counters, no signal from one or two Čerenkov counters, and a decay signal from any one of four scintillation counters at the sides of an aluminum block in which the K mesons are brought to rest.[1] The contribution to the yield from the process $\gamma + p \rightarrow K^+ + \Lambda^0$ is determined by lowering the end point of the bremsstrahlung spectrum below the Σ^0 threshold. Preliminary analysis gives cross sections in the center of mass of (0.74 ± 0.10), (1.09 ± 0.18), and $(0.55 \pm 0.13) \times 10^{-31}$ cm^2 per sr per photon at center-of-mass angles of 30°, 85°, and 120°, respectively.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Now at Brookhaven National Laboratory.
[1] B. D. McDaniel, A. Silverman, R. R. Wilson, and G. Cortellessa, Phys. Rev. 115, 1039 (1959).

N7. K^--Meson Interactions Yielding Hyperfragments in Light and Heavy Nuclei of Emulsions.* OLIVER E. OVERSETH, JR., *Princeton University.*—An analysis has been made of 100 K^--meson interactions at rest in emulsions resulting in the emission of hyperfragments. The attempt has been made to separate the events into absorptions on the light and on the heavy nuclei of the emulsion. The energy distribution of the α-particles emitted from these K^- stars exhibits two maxima separated by a minimum at about 8 Mev corresponding to the Coulomb potential barrier for α emission from the heavy nuclei. All K^- stars emitting an α particle with energy less than 8 Mev are classified as due to K^- absorption on a light nucleus, while the presence of Auger electrons generally indicates absorption by a heavy nucleus. It is found that between 40% and 70% of the K^- interactions yielding observable hyperfragments occur in the light elements of the emulsion. The difference in

frequency of emission of a fast π meson in the two classes of nuclei will be used to improve this estimate. Characteristics of the events classifiable into these two groups will be compared. A similar separation of K^- interactions not yielding hyperfragments has been made for comparison.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

N8. Properties of the Lambda-Pion Resonance as Observed from the K_2^0-p Interaction.* H. J. MARTIN,† W. CHINOWSKY,‡ AND L. B. LEIPUNER, *Brookhaven National Laboratory*, AND F. T. SHIVELY AND R. K. ADAIR, *Yale University*.—Additional evidence concerning properties of the recently reported pion-hyperon resonance[1] Y^* has resulted from a study of the interaction $K_2^0+p \rightarrow Y^*+\pi$, where $Y^* \rightarrow \Lambda^0+\pi$, as observed in a 100 000-picture run using a 14-in. liquid hydrogen bubble chamber. The K^0 beam, produced by allowing a 1600-Mev/c π^- meson beam from the Brookhaven Cosmotron to strike a polyethylene target, appeared to have an intensity of about 2 K^0/pulse with a broad momentum spectrum centered about 1100 Mev/c. An analysis of about 70% of the data has resulted in the identification of about 70 events as $\Lambda^0+\pi^++\pi^0$. Observed momenta were used to calculate the Q-values for (Λ^0,π^0) and (Λ^0,π^+) systems. About 75% of the events resulted in Q values which formed a sharp peak at an energy corresponding to a Y^* mass of about 1385 Mev with a width less than 20 Mev. These are evenly divided between (Λ^0,π^0) and (Λ^0,π^+) events in accord with charge independence of the interaction. Analyses, as yet incomplete, will be presented concerning the spin and parity of the state.

* Research performed under the auspices of the U. S. Atomic Energy Commission.
† On leave from the University of Indiana.
‡ On leave at the University of California at Berkeley.
[1] Reported by M. L. Good at the 10th Rochester Conference on High-Energy Nuclear Physics (1960).

N9. $\Lambda\pi$ Resonance and Low-Energy K^-p Reactions. MARC H. ROSS,* *Universita di Roma*, AND GORDON L. SHAW, *University of California, La Jolla*.—By using our multichannel effective range formalism,[1] a survey of s wave $\overline{K}N$ reactions is made which is consistent with the low-energy K^-p data. In particular, we investigate situations which yield a resonance in the isotopic spin $I=1$ state at an energy 50 Mev below the $\overline{K}N$ threshold with a width of about 75 Mev; it has been proposed[2] that this is the $\Lambda\pi$ resonant state recently observed in experiments[3] at Berkely on the reaction $K^-+p \rightarrow \Lambda+\pi^-+\pi^+$. Curves will be shown displaying the large role that the effective range terms play. The effect of the KYN parities in decreasing the $(\Sigma/\Lambda)_{I=1}$ ratio from the observed at-rest ratio of the order of 1 to a value $\ll 1$ at an energy corresponding to the resonance will be displayed.

* On leave from Indiana University, Bloomington, Indiana.
[1] M. Ross and G. Shaw, Ann. Phys. (to be published).
[2] M. Ross and G. Shaw (to be published).
[3] Alston *et al.*, 10th International Conference on High-Energy Nuclear Physics, Rochester (1960); Ferro-Luzzi *et al.*, UCRL-9431 abstract.

N10. Σ^- Capture Stars and $\Lambda-N$ Elastic Cross Section. YONG W. KANG AND JACK SCHNEPS, *Tufts University*.—Σ^- stars in nuclear emulsion were analyzed in order to estimate the $\Lambda-N$ elastic cross section according to the calculation of Biswas and Ceccarelli[1] and to study characteristics such as prong distribution, visible energy distribution, Auger electron production, and excitation energy. The determination of the $\Lambda-N$ cross section from the prong distribution depends sensitively on the number of zero prong stars. In order to determine this we used only Σ^- which came from K^- captures on hydrogen. From 55 K^- captures on hydrogen there were 33 Σ^- which made stars. Of the 33 Σ^- stars, 12 were zero prong so the percentage of Σ^- zero prong stars is 36 ± 11%. Nine of these 12 have an accompanying Auger electron. These data suggest a somewhat higher value for the $\Lambda-N$ elastic cross section than that estimated from a collection of experimental data in the paper of Biswas and Ceccarelli. Among the 242 one-or-more pronged Σ^- stars coming from all the K^- stars in our stack, there were 13 hyperfragments, all GOKS. Estimating the number of zero-prong stars to be 36%, as indicated above, the rate of hyperfragment production is $13/378=3.4$%. Data will be presented on Auger electron production and excitation energy in Σ^- stars.

[1] N. N. Biswas and M. Ceccarelli, Nuovo cimento **8**, 599 (1958).

N11. Binding Energies of Mesic Hypernuclei.* Y. PRAKASH, P. H. STEINBERG, D. A. CHANDLER, AND R. J. PREM, *University of Maryland*.—A stack of 150, G5 emulsion (6-in.$\times$4-in. $\times 600\,\mu$) pellicles exposed to 300 Mev/c K^- mesons at the Bevatron was area-scanned for mesic hypernuclei from K^- captures. Out of 89 events found, 76 could be measured completely. Preliminary results on the binding energies for uniquely identified events are in good agreement with previously reported values.[1,2] Of particular interest are the following decays: (1) ${}_\Lambda He^7 \rightarrow He^4+H^3+\pi^-$; $B_\Lambda=(3.0\pm0.7)$ Mev and (2) ${}_\Lambda He^5 \rightarrow He^3+H^2+\pi^-$; $B_\Lambda=(3.3\pm0.3)$ Mev. One example of decay in flight of ${}_\Lambda H^4$ has been observed with a flight time $\approx 0.9\times10^{-12}$ sec.

* The work is supported by the U. S. Atomic Energy Commission.
[1] R. Ammar *et al.*, Nuovo cimento **XV**, 181 (1960).
[2] R. Levi Setti *et al.*, Nuovo cimento (Suppl.) **X**, 68 (1958).

N12. Two-Meson Annihilations of Antiprotons in Hydrogen.* G. R. LYNCH, J. BUTTON, P. EBERHARD, G. R. KALBFLEISCH, J. E. LANNUTTI, B. C. MAGLIC, M. L. STEVENSON, AND NGUYEN H. XUONG, *Lawrence Radiation Laboratory, Berkeley*.—Among 20 300 interactions of 1.61-Bev/c antiprotons in the 72-in. hydrogen bubble chamber, 20 events of the reaction $\bar{p}+p \rightarrow \pi^++\pi^-$ and 11 events of the reaction $\bar{p}+p \rightarrow K^++K^-$ have been observed, yielding the cross sections of $100\pm25\,\mu$b for $\pi^+\pi^-$ and $55\pm18\,\mu$b for K^+K^-. The angular distribution of the pion is consistent with isotropy; however, the negative kaon angular distribution is strongly peaked forward.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

FRIDAY MORNING AT 10:00

New Yorker, Panel Room

(F. N. FRENKIEL presiding)

Fluid Dynamics

NA1. Start-up Flow between Parallel Plates.* STEPHEN J. LUKASIK AND J. W. NEMISH, *Stevens Institute of Technology*.—The start-up flow between parallel plates has been studied using the electrolytic bubble technique[1,2] in order to obtain the time-varying velocity profile. The test section in which the measurements were made had a cross section $\frac{3}{4}$ in.$\times$6 in. and

was connected to a large water reservoir; the device was operated as a blow-down water tunnel. The mean fluid velocity was of the order of 1 cm/sec corresponding to a Reynolds number of 137. Velocity profiles were determined at 0.38, 1.35, and 6.66 sec after the start of the flow. It was observed that this last profile agreed closely with the asymptotic solution for parallel plate flow. The problem has been examined theoretically, and a comparison with the data will be shown.

* Work supported by the U. S. Navy, Bureau of Ships.
[1] E. W. Geller, M. S. Thesis, Mississippi State University (1954).
[2] S. J. Lukasik and C. E. Grosch, Bull. Am. Phys. Soc. Ser. II, 5, 133 (1960).

NA2. Effect of Flexible Walls on the Stability of Plane Poiseuille Flow. F. D. HAINS AND J. F. PRICE, *Boeing Scientific Research Laboratories.*—Calculations have been made of the stability of Poiseuille flow between parallel walls which are flexible and acted upon by a distributed spring and viscous damper. The walls, which are assumed to be thin membranes, are initially at rest and lie parallel to the flow direction. Infinitesimal disturbances are introduced which cause pressure fluctuations in the flow, resulting in oscillations of the walls. Stability depends on the membrane constant which is a function of the applied tension, the mass per unit length of the membrane, the spring constant, and viscous damping coefficient. The Orr-Sommerfeld equation was solved numerically for a range of values of the membrane constant by a technique similar to Thomas.[1] Results indicate an increase in critical Reynolds number can be achieved by wall damping.

[1] L. H. Thomas, Phys. Rev. 91, 780 (1953).

NA3. Calculation of Nonequilibrium Flows with Attached Shock Waves. J. C. SOUTH AND R. SEDNEY, *Ballistic Research Laboratories* (introduced by F. D. Bennett).—The numerical solution by the method of characteristics for the nonequilibrium flow over bodies with attached shock waves is discussed. Specifically the case of the vibrational relaxation of a diatomic gas is considered. The success of the method depends on the proper choice of independent variables. For flow of N_2 over a 40° wedge at $M=6$ and STP the shock wave angle changes by 2.8°. Ninety-nine percent of this change has occured within a distance of 0.475 in. from the tip. Along the wedge surface the equilibrium state attained is not the same as that behind the equilibrium oblique shock. The difference amounts to 5% in entropy, 4% in density, and 4% in temperature whereas the pressure is the same. This behavior can be made plausible by an approximate, partial solution of the governing equations. These results show that, far from the tip, there will be an "entropy layer" near the body; across this layer the stagnation pressure changes by 16%. It appears that this observation can be made the basis for a technique of measuring relaxation time.

NA4. Shock Tube Driven Molecular Beam for the 1–10 ev Range.* G. T. SKINNER, *Cornell Aeronautical Laboratory, Inc.* (introduced by C. E. Treanor).—A small tailored interface hypersonic shock tunnel, consisting of shock tube and two-stage expansion nozzle, is being used as a "source" for an atomic or molecular beam. Such a source provides a stream of high-velocity particles at low ambient temperature, giving a high degree of energy collimation. Dissociation products in the shock tube can be preserved intact by operating at moderately low density and allowing gas composition to "freeze" early in the expansion. The beam is defined by a collimating orifice placed in the hypersonic flow at a point where the mean free path is large compared with the orifice diameter. The beam intensity is of the order of 10^{19} molecules cm^{-2} sec^{-1}. In passing such an intense stream of high-energy particles through a "cold" orifice, certain problems arise from collision processes which can be neglected in conventional molecular beams. These are essentially rarefied gas dynamic phenomena. The present apparatus gives a well-defined beam for several diameters downstream of the orifice.

* This work is supported by the U. S. Air Force Office of Scientific Research.

NA5. Shock Waves in Radiation-Magnetogasdynamics.* S. I. PAI AND A. I. SPETH, *University of Maryland.*—The general Rankine-Hugoniot relations of a shock wave including both the electromagnetic forces and the radiation effect are presented. These results differ considerably from those without radiation effect. It has been known that if the shock strength is very large, the radiation effect on the shock wave is noticeable. From our results, we have found that even the shock strength is very weak; the shock wave relations with radiation effect differ considerably from those without radiation effect, provided that the initial temperature of the medium is very high and that the radiation parameter is not small. The main effect of radiation on the shock wave is that the jump of temperature across a shock is reduced greatly because of the radiation effect. Some numerical examples will be presented.

* Supported by the U. S. Air Force Office of Scientific Research.

NA6. Local Supersonic Region on a Body Moving at Subsonic Speeds. E. V. LAITONE, *University of California, Berkeley.*—A theoretical analysis is made of the compressible inviscid potential flow about a two-dimensional profile having a sufficiently large subsonic free-stream Mach number so as to form a local supersonic region over its central portion. It is found that the local velocity on the body surface cannot exceed $a_*\sqrt{2}$ unless there is a discontinuity in the radius of curvature of the body profile at this location. This difficulty arises because the Mach lines must always form an inflection point at this particular velocity magnitude. It is then shown how this limits the forward inclination of the Mach lines and thereby limits the maximum velocity unless there is a discontinuity in the surface curvature. This velocity limitation is somewhat analogous to the sonic velocity limit in a Laval nozzle because signals cannot be propagated further upstream by a smooth continuous profile.

NA7. Interaction of Low-Frequency Electromagnetic Waves with a Conducting Gas. DONALD L. TURCOTTE, *Cornell University.*—The interaction of a low-frequency electromagnetic wave with a semi-infinite body of conducting gas is considered. The electromagnetic wave propagates parallel to the plane which divides the gas from free space. The magnetic component of the electromagnetic wave is assumed to be a perturbation on a strong uniform magnetic field. The magnetic vector also lies parallel to the dividing plane. An exact solution of the skin-depth problem is obtained from the linearized M−H−D equations if (1) the velocity of sound is much greater than the Alfven velocity and (2) if the velocity of sound is much less than the Alfven velocity. In the first case the solution for a solid conductor is obtained. In the second case the interaction between the electromagnetic wave and the conductor is weak; the wave propagates very nearly as though the conductor was not present.

NA8. Momentum Dynamics of Gas-Phase Physical Processes. W. D. WEATHERFORD, JR., *Southwest Research Institute* (introduced by William Squire).—A new method has been developed for predicting and correlating kinetic processes which are involved in phenomena such as molecular collision frequency, molecular diffusion, and viscosity. This method utilizes the kinetic theory type of derivation, but considers gas particles as hard spheres, each with a variable sphere of mutual interference. Both variation in size of the sphere of interference and frequency of interference occurrences are specified in terms analagous to the particle wavelength and frequency described by De Broglie. Therefore, the method may be con-

sidered as a blending of the kinetic theory with the principles of atomic physics. Examples showing the application of the method to ideal gases suggest that the uncertainties of the classical kinetic theory may be circumvented easily without significant increase in mathematical complexity.

NA9. Implosive Phase of a Spherical Explosion in Sea Water. S. A. BERGER, *Princeton University*, AND MAURICE HOLT, *University of California, Berkeley.*—The calculation of the development of a spherical explosion in sea water, due to the symmetrical detonation of a charge of PETN, is carried up to the stage when the second blast wave converges as an implosive wave on the center and is reflected. Continuing earlier calculations by the authors, the complete field of disturbance is determined by the Eulerian approach, using the numerical method of characteristics and boundary fitting techniques, up to the characteristic ray originating from the center at the time of implosion. At this ray the main shock has traveled approximately 14 charge radii from the center. The implosive phase of the second shock motion is a well-known similarity phenomenon, and a variety of methods for treating this are discussed.

NA10. Electrical Resistivity during a Detonation.* SAMUEL KOSLOV, STEPHEN J. LUKASIK AND BENJAMIN J. PERNICK, *Stevens Institute of Technology.*—Measurements of surface electrical resistivity in the detonation zone of pentolite and composition *B* have been made. Two probe geometries were employed; one consisted of two copper plates oriented to resemble the letter T, one plate having its flat side against an explosive face, the other plate having its thin edge placed against an opposite face. The second type consisted of two parallel copper wires mounted in a ceramic insulator with the wire ends butted against an explosive face. The resistance of the probe when the detonation zone reaches its edges is measured by recording the transient current under an applied external voltage. The explosive resistivity ρ is calculated from the measured resistance R by using the relation $\rho = \text{const} \times R$. For the T probe this constant is calculated from the known explosive geometry. For the double probe this constant is evaluated by calibration in a material of known conductivity. Resistivity values of the order of 1 ohm-cm have been obtained from both probe types. Estimates of the thickness of the reaction zone and the free electron density have been made.

* Work supported by the Ordnance Corps, U. S. Army, and carried out in conjunction with Dr. E. N. Clark, Explosives Research Section, Picatinny Arsenal, Dover, New Jersey.

NA11. Ratio of Dielectric Constant across a Shock Front in Barium Titanate. P. S. BRODY AND R. H. WITTEKINDT, *Diamond Ordnance Fuze Laboratories.**—Experimental values of the ratio of the dielectric constants across a shock front in polarized elements of barium titanate ceramic have been inferred from oscillographic records of voltage. The elements were right cylinders polarized in the axial direction with fired silver electrodes on the cylinder ends. The shock front produced by a high-velocity impact moved axially and voltage generated across a 10-ohm resistor connecting the electrodes was recorded. The shock pressure was obtained from the impact velocity and the shock-particle velocity relation for the impacted and impacting materials. An expression is obtained for the voltage in terms of the ratio of the dielectric constants across the shock front and the resistivity behind, assuming that the material behind the shock front has a uniform resistivity, a uniform dielectric constant, no spontaneous polarization, and the induced polarization is linear with the field. Comparison of experiment and theory indicates that measured at 100 kilobars the ratio of the dielectric constants is about 2 and that the resistivity is 10^4 ohm-cm or greater.

* Placed in the fluid dynamics session at the authors' reques

Business Meeting of the Division of Fluid Dynamics

FRIDAY MORNING AT 9:45

New Yorker, Terrace Room

(V. W. HUGHES presiding)

Invited Papers in Low-Energy Nuclear Physics

O1. Direct Reactions in Mirror-Nuclei and the Two-Body Problem. S. D. BLOOM, *Lawrence Radiation Laboratory, Livermore.* (30 min.)

O2. Circular Polarization of Nuclear Gamma-Rays and Isotopic Spin Conservation. LLOYD MANN, *Lawrence Radiation Laboratory, Livermore.* (30 min.)

O3. Nuclear Collective Motion and the Shell Model. MICHEL BARANGER, *Carnegie Institute of Technology.* (30 min.)

O4. Nuclear Molecules. D. A. BROMLEY, *Yale University.* (30 min.)

FRIDAY MORNING AT 9:30

Martinique, Empress Josephine Room

(P. MORRISON, presiding)

Theoretical Physics IV: Classical and Quantum Theory

OA1. Is Space-Time Necessarily 3+1 Dimensional? JEROME ROTHSTEIN, *Edgerton, Germeshausen and Grier, Inc.*—Dimensionality is a topological invariant logically prior to particular metrics; hence physical dimensionality should arise earlier than in usual discussions of foundations. Assume a universe such that (a) information is obtainable about it, (b)

some information is objective in the sense that agreement is possible between communicating observers otherwise independent. From (a) one gets ordered sequences, "subjective time," and isomorphic subsets of "subjective space"; from (b) the common structure permitting agreement must be dense subsets of at least 1+1 dimensional continua becoming at least 2+1 to avoid mutual interference of observers. Coordinates are introducible in many equivalent ways describing the same information, some corresponding to the different observers. Objectivity requires algebraic as well as topological invariance properties. A set of mathematical objects is generated forming a topologized algebraic field satisfying the second axiom of countability; it is of the same dimensionality as the manifold of objective events. As such, a set is necessarily isomorphic to one of three fields, the real numbers, the complex numbers, or the real quaternions, with respective dimensionality 1, 1+1, 3+1; the framework of classical physics is necessarily 3+1 dimensional. Admissible micro-geometries must generate (3+1) space-time in a correspondence-principle sense.

OA2. Killing Vectors and Observables in General Relativity.* ALLEN I. JANIS, *University of Pittsburgh*.—Komar's treatment of the observables of general relativity in terms of intrinsic coordinate systems presupposes a space admitting no Killing fields. This approach is extended to permit the identification of observables when Killing fields are present, subject, however, to certain restrictions on the minimum invariant varieties. The method can be applied to some of the well-known metrics.

* Supported in part by Wright Air Development Division, U. S. Air Force.

OA3. Scalar Invariants and Groups of Motions. ROY P. KERR, *Aeronautical Research Laboratory* (introduced by W. J. Price).—It has been conjectured that there should be a strong connection between the number of functionally independent Killing vectors (q) and the number of functionally independent scalars (N) in an n-dimensional Riemann space. Obviously, $q \leq n-N$. We prove that in a four-dimensional Einstein space the equality holds, $q=N$. Also, we show that the dimension of the group of motions, i.e., the number of linearly independent Killing vectors is $q+r$, where r is the dimension of the group of rotations, at a point, preserving the numerical values of the Riemann tensor and its covariant derivatives. These results relate the integrability conditions for Killing's equation with the algebraic properties of the curvature tensor and its derivatives.

OA4. Effect of Azimuthal Asymmetry in the Explosion Model of the Expanding Universe. WINSTON H. BOSTICK, *Stevens Institute of Technology*.—The spherically symmetrical, nonrelativistic explosion model of the expanding universe (e.g., the treatment by Hoyle[1]) gives the velocity $\mathbf{v}(\mathbf{n},t)$ as $\mathbf{v}^0=[(8\pi G\rho/3)-(k/R_0)]\mathbf{n}^0$, where G is the gravitational constant, ρ is the matter density, R the radius of the periphery, and $k<0$, $=0$, >0 corresponds, respectively, to a hyperbolic, parabolic, or elliptic universe. For the simple case, $k=0$, $\mathbf{v}=2\mathbf{n}/3t$, $\rho=1/6\pi Gt^2$, and $R\cong 8.5\times 10^{16}t$ cm. A small azimuthal perturbation $(R_1-R)/R$ occurring on this otherwise spherically symmetrical model grows with t as $(R_1-R)/R=0.8\times 10^{-32}|k_1|t^4$, where k_1 is the value of k in the perturbation. Thus with this simple nonrelativistic model, a perturbation of one part in 10^4, occurring when the universe was only 10^{-6} as old as it is now, would by now have grown to a perturbation of value equal to 1, which would be sufficient distortion for the universe to undergo fission.

[1] F. Hoyle, Monthly Notices Roy. Astron. Soc. **108**, 372 (1948).

OA5. Lower Bounds for Eigenvalues of the Schrödinger Equation. N. W. BAZLEY, *National Bureau of Standards*, AND D. W. FOX, *Applied Physics Laboratory, The Johns Hopkins University* (introduced by J. P. Vinti).—Our method for obtaining lower bounds is based upon the work of A. Weinstein, N. Aronszajn, and H. F. Weinberger. Let E_i and ψ_i denote the eigenvalues and wave functions of the Schrödinger equation $H\psi=E\psi$; here $E_1\leq E_2\leq E_3\cdots$ where each degenerate energy level appears in the sequence the number of times of its multiplicity. Assume that $H=H^0+H'$ where $(H'\psi,\psi)=\int(H'\psi)\psi^* d\tau\geq 0^0$; further let $H^0\psi_i^0=E_i^0\psi_i^0$ have known solutions $E_i^0\psi_i^0$ ordered as $E_1^0\leq E_2^0\leq E_3^0\cdots$. We introduce the Hamiltonian operators $H^{l,k}=H^{0,l}+(H')^{\frac{1}{2}}P^k(H')^{\frac{1}{2}}$. Here P^k is the projection operator on arbitrary vectors $p_1,\cdots,p_k$; $(H')^{\frac{1}{2}}$ satisfies $H'=(H')^{\frac{1}{2}}(H')^{\frac{1}{2}}$; $H^{0,l}\psi_i=H^0\psi_i (i=1,\cdots,l)$; and $H^{0,l}\psi_i=E_{i+1}^0\psi_i (i\geq l+1)$. It follows that $(H^{l,k}\psi,\psi)\leq(H\psi,\psi)$ for any ψ; hence, $E_i^{k,l}\leq E_i (i=1,2,3\cdots)$, where $H^{l,k}\psi_i^{l,k}=E_i^{l,k}\psi_i^{l,k}$. The rigorous lower bounds $E_i^{l,k}$ can be computed in terms of the matrix elements $(H'\psi_i,p_t)$, $(H'p_t,p_s)$, and $(H'p_t,H'p_s)$ for $(1\leq i\leq l)$ and $(1\leq t,s\leq k)$. The wave functions $\psi_i^{l,k}$ also are found and approximate ψ_i when p_i approximates ψ_i. The theory allows for continuous energy states. This method is applicable to any atomic system and is now being applied to estimate ground and excited states of the helium atom.

OA6. Spin Precession in Classical Relativistic Mechanics. H. C. CORBEN, *Space Technology Laboratories*.—Solutions are obtained for the motion of a spinning particle according to classical relativistic point-particle mechanics.[1] The polar vector components of the spin tensor are assumed to vanish in the rest system, and radiation reaction terms are neglected. It is found that the momentum and velocity are not necessarily parallel and that a free particle may move along a helix. During such motion the sum of the intrinsic spin σ and the angular momentum of the helical motion is an effective constant spin vector s which is automatically parallel or antiparallel to the momentum p. The rest-mass times the magnitude of the rest-spin divided by the component of s in the direction of p has the property of an effective mass M for the particle, the sign of M thus being determined by the helicity. For $p=0$ the particle moves in a circle of radius $\beta\sigma/Mc$ with angular velocity given by $\sigma\Omega=Mc^2$. In the presence of a uniform static field the particle if charged behaves as if it had a mass M and a magnetic moment $e\sigma/Mc$, provided that no explicit magnetic moment has been ascribed to it.

[1] H. J. Bhabha and H. C. Corben, Proc. Roy. Soc. (London) **A178**, 273 (1941).

OA7. Scattering from a Penetrable Sphere at Short Wavelengths. S. I. RUBINOW, *Stevens Institute of Technology*.—A scalar plane wave incident on a penetrable sphere is considered in the short wavelength limit. A new representation of the scattering amplitude is introduced which is particularly appropriate in this limit and which requires only the evaluation of certain integrals. Some of these may be evaluated asymptotically by the method of steepest descent and lead to the geometrical optics field contribution. Included in this is the bow field. The remainder of the integrals are evaluated by the method of residues and lead to the diffracted field contribution. This "diffracted ray" field is known from recent investigations in diffraction theory. An essential part of the analysis is the introduction of the parameter p, the number of internal refractions that a ray which hits the sphere undergoes. The results obtained are all in agreement with that which would be expected on the basis of geometrical diffraction theory.

OA8. Quasi-Classical Theory of the Dirac Equation.* RALPH SCHILLER,† *Syracuse University*.—In a recent technical report entitled "Quasi-Classical Theory of the Pauli Equation" (unpublished) we developed a new WKB approximation for

the Pauli equation. We have since extended the method to the second-order Dirac equation. The method consists in adopting a suitable classical model of a spinning electron and showing that a specially constructed Hamilton-Jacobi theory of our classical equations permits us to find a classical spinor which satisfies an equation differing from the Dirac equation by terms in $\hbar^2$. For the Kepler problem the theory yields those constants of the motion expected from the Dirac theory, and it is hoped that it will yield the exact quantum eigenvalues when the theory is quantized by the usual WKB theory. If this WKB theory predicts the same eigenvalues as the Dirac theory, then there exists a canonical transformation which transforms our classical equation into an exact equation of quantum mechanics.

* Supported by the Office of Naval Research.
† On leave from Stevens Institute of Technology.

OA9. Homotopy Groups and Elementary Particles. S. L. GREENE, *Syracuse University* (introduced by A. O. Barut).—There exist only four known stable particles: the photon γ, neutrino ν, electron e, and proton p. Consider these to be representations of the members of a four-element fundamental homotopy group H_4, with the photon representing the unit element of H_4, and $\bar{\nu}$, $\bar{e}$, $\bar{p}$ representing the respective inverses of ν, e, p. Thus $e+\bar{e}=\gamma$, corresponding to the fact that multiplication of a member of H_4 by its inverse gives back the unit element. Then the instability of Λ, π, etc., proceeds from homomorphisms of the fundamental groups of these particles with the fundamental group of the stable particles, the kernel of this homomorphism being the class of processes which map into the unit element of the fundamental group of the stable particles, i.e., the photon. Boson statistics for the photon appear as the statement that any number of unit elements are compatible. The space and momentum independent character of the quantum numbers of elementary particles corresponds to the existence of equivalence classes of curves in the topological space which is the substratum from which the homotopy group was abstracted.

OA10. Derivation of Delta-Function Singularity in Spin-Spin Interaction.* KOICHI MANO, *Wentworth Institute*.—The occurrence of the delta-function singularity in the spin-spin interaction of the two-electron system has been shown clearly by Bethe and Salpeter.[1] This has been carried out by advantageously making use of the momentum space as the intermediate step. The proof seems, however, to possess certain misleading features in it. It is proposed here to put the account of the derivation of the delta-function singularity on a more readily acceptable basis.

* Supported by the Geophysics Research Directorate, U. S. Air Force Cambridge Research Laboratories, Air Force Research Division.
[1] H. Bethe and E. E. Salpeter, *Encyclopedia of Physics* (Springer-Verlag, Berlin, 1957), Vol. XXXV, Sec. 39.

OA11. Time Development of a Quasi-Stationary State.* ROLF G. WINTER, *The Pennsylvania State University*.—It is known that quasi-stationary states decay exponentially only for intermediate times and that, eventually, the decay rate varies as a negative power of the time. The usual approximation methods fail, however, in regions of very early times and of transition from exponential to power-law behavior. To gain a complete picture, we have studied with a digital computer the development of a wave function in the same delta-function barrier penetration problem discussed before by approximate analytical methods.[1] The decay rate oscillates at very early times and then follows approximately exponential behavior for a large middle region of time. It then oscillates violently, with dips to negative values for high-transmission barriers. Finally, the oscillations cease in the region of large-time power law behavior. These remarkable oscillations are sensitive to details of the initial wave function and will be smoothed in most experiments because the decaying system is, in practice, a mixture of slightly different wave functions.

* Supported in part by the Office of Ordnance Research, U. S. Army.
[1] Rolf G. Winter, Bull. Am. Phys. Soc. Ser. II, 5, 64 (1960).

OA12. Method for Calculating the Principal Modes of Nonlinear Systems Utilizing Infinite Determinants. DEMETRIOS G. MAGIROS, *Republic Aviation Corporation* (introduced by L. Brillouin).—The concept of "principal modes" plays the predominant role in the analysis of oscillatory systems, no matter what field the systems occur in. The definition of principal modes of linear systems as the set of fundamental solutions of which a linear combination gives the general solution of the linear system does not hold in nonlinear systems, since, in these systems, the "principle of superposition" does not hold. The study of the principal modes of systems, either linear or nonlinear, may be made by using two definitions, namely the "proportionality definition" of principal modes and their definition as solutions of special "initial value problems." Calculations, based on these definitions, are shown for a nonlinear "dual-mode" system where the solutions of the equations, which govern the motion of the nonlinear system, are assumed to have the form of exponential series with complex coefficients, and the calculation of the "principal frequency" and the coefficients of the series lead to "infinite determinants." The analysis of the special class of the "infinite determinants" involved completes the method. Both approaches have the same physical interpretation.

OA13. Electromagnetic Sources in General Relativity Theory.* T. R. WAITE, *Atomics International*.—The simplest most direct method of unifying Maxwell's theory of electromagnetism and Einstein's theory of gravitation was formulated by Rainich in 1925. That theory, however, applies only to charge free space. It has been shown that, in regions of space in which the electromagnetic field invariant corresponding to $\vec{E}\cdot\vec{B}$ vanishes, the two sets of Maxwell's equations are independent for Rainich's unified theory. In such regions the charge and current density may not vanish. The electromagnetic sources and fields obey Maxwell-Lorentz theory, and the electromagnetic matter-energy obeys the laws of Einstein's general relativity theory. The necessary and sufficient conditions which one must impose on the metric tensor and its derivatives in order to assure the existence of a unique antisymmetric tensor obeying the Maxwell-Lorentz laws in the presence of charges and currents have been derived.

* This work was initiated while the author was a National Science Foundation Post-Doctoral Fellow in the Physics Department, California Institute of Technology, Pasadena, California.

OA14. Remarks about Einstein's Considerations in Regard to the Hamilton-Jacobi Theorem. HERBERT JEHLE, *George Washington University*.—By starting from Hamilton's canonical equations, and using the properties of canonical transformations, one arrives at the H. J. theorem stating that an orbit in classical mechanics is characterized by $p_i=\partial S/\partial g^i$, $\beta_k=\partial S/\partial \alpha^k$, where $S=S(g^i,\alpha^k,t)$ is a complete solution of the H. J. equation $\partial S/\partial t=-\bar{H}(g^i,\partial S/\partial g^i,t)$, and $\bar{H}(g^i,\partial S/\partial g^i,t)=H(g^i,p_i,t)$. Without referring to properties of canonical transformations (and again starting from Hamilton's canonical equations), Einstein gave an elegant consideration of this theorem by asking the question whether there are irrotational streaming fields $p_i=p_i(g^i,\alpha^k,t)$ satisfying the canonical equations. The irrotationality implies $p_i=\partial S/\partial g^i$. With p_i being considered as a streaming field, the canonical equations yield

$$0=\partial H/\partial g^i+\dot{p}_i=\partial H/\partial g^i+\partial p_i/\partial t+\Sigma\,(\partial p_i/\partial g^l)\dot{g}_l$$
$$=\partial p_i/\partial t+\partial H/\partial g^i+\Sigma\,(\partial p_l/\partial g^i)\partial H/\partial p_l$$
$$=\partial p_i/\partial t+(\partial/\partial g^i)\bar{H}=(\partial/\partial g^i)(\partial S/\partial t+\bar{H}),$$

which is satisfied by $0=\partial S/\partial t+\bar{H}(g^i,\partial S/\partial g^i,t)$. Let

$$S=S(g^i,\alpha^i,t)$$

be a complete solution. Then

$$0=(\partial/\partial\alpha^i)(\partial S/\partial t+\bar{H}(g^l,\partial S/\partial g^k,t)$$
$$=\partial^2 S/\partial\alpha^i\partial t+\Sigma\,(\partial H/\partial p_k)\partial^2 S/\partial\alpha^i\partial g^k$$
$$=(\partial/\partial t+\Sigma\,\dot{g}^k\partial/\partial g^k)\partial S/\partial\alpha^i,$$

which means $\partial S/\partial\alpha^i=$const along an orbit, $=\beta_i$. This reasoning suggests interesting connections with Feynman's method of path integrals.

[1] A. Einstein, Sitzber. preuss. Akad. Wiss., Physik.-math. Kl. 606 (1917).

FRIDAY MORNING AT 10:15

Statler-Hilton, Terrace Ballroom East

(R. L. GARWIN presiding)

Apparatus of Nuclear Physics

P1. High-Current Positive Ion Source with Mass Analysis. A. B. WITTKOWER, R. P. BASTIDE, AND P. H. ROSE, *High Voltage Engineering Corporation.*—Positive hydrogen ions extracted from a duoplasmatron ion source by a high potential were deflected through 45° by a magnet. The H_1^+, H_2^+, and H_3^+ components of the beam could be separated with $\ll 1\%$ cross contamination. By changing the source operating conditions, particularly the gas pressure, it was possible to optimize a particular beam mass. For example, 83% of the total beam current could be concentrated in the H_2^+ component. At 50 kev, a maximum H_2^+ beam of 30.6 ma, measured calorimetrically, could be focused by a 2.0-in. diameter Einzel lens to a diameter of 0.8 in. at a distance of 26 in. from the source aperture. The source aperture in this case was 0.052-in. diam. The expected relationship $I_{\max}\propto E^{\frac{1}{2}}$ accurately described the yields at other extraction voltages. Beam neutralization by the residual gas in the system gave a spot diameter smaller than that expected from space-charge repulsion theory. A negatively biased guard ring between the Einzel lens and the magnet, to prevent the loss of slow electrons trapped in the beams, was found to reduce the beam diameter by approximately 25%. The performance of this source will be compared to published results of other workers.

P2. Simplified Theory of the Quadrupole Mass Filter.* WILSON M. BRUBAKER, *Bell & Howell Research Center.*—It has been shown that the quadrupole electric field can be used as a mass filter with variable band-pass characteristics.[1,2] The formal solution of the equations of motion of the ions as they pass through the mass filter is given by the Mathieu equation, expressed as an infinite series. This solution is most difficult to interpret and use. An approximate solution of the Mathieu equation is derived. It is in excellent agreement with the formal solution over the limited portion of the stability diagram which is applicable to mass spectrometry. The derivation follows directly from the application of Newtonian mechanics, and it leads to a clear physical picture of the nature of the ionic trajectories. The solution permits a ready derivation of the operational characteristics of the mass filter as functions of the many independent parameters.

* This work was supported by the U. S. Air Force Cambridge Research Center.

[1] W. Paul and M. Raether, Z. Physik 140, 262 (1955).
[2] W. Paul, H. P. Reinhard, and U. von Zahn, Z. Physik 152, 143 (1958).

P3. Precision Current Control Circuit for a Large Charged Particle Deflection Magnet.* R. C. MOBLEY, *Louisiana State University.*—A closed servo loop consisting of a chopper stabilized dc electronic amplifier, a two-stage single-phase magnetic amplifier, a current sensing standard resistor, and a potentiometer bucking voltage source has served reliably over the past 5 yr as the variable, precision regulated, current source for an Ion Buncher[1] charged particle deflection magnet. Controlled current range is from 5 to 200 amp at up to 40 v. Appropriate feedback loops permit an essentially critically damped 0.01% control and regulation response throughout the entire current range. A heavy aluminum vacuum box surrounding the magnet pole pieces and solid copper forms on which the excitation coils are wound reduce power supply ripple effect on the magnet's field to less than 0.01%. Complications of a multiphase magnetic amplifier therefore are avoided.

* Supported in part by the U. S. Atomic Energy Commission.
[1] R. C. Mobley, Phys. Rev. 88, 360 (1952).

P4. Semiempirical Method for Calculating Gamma-Ray Detection Efficiencies of NaI Crystals. P. P. SINGH[1] AND G. M. GRIFFITHS, *University of British Columbia.*—In principle, the method consists of determining the efficiency above a selected bias by evaluating the contribution, above and below this bias, due to primary absorption processes and then correcting for secondary absorption processes in the crystal and escape of electrons and secondary quanta from the walls and the edges of the crystal. To check the results of this method absolute efficiencies were determined at 0.5, 1.25, and 6.14 Mev using γ rays from Na^{22}, Co^{60}, and the $F^{19}(p,\alpha\gamma)O^{16}$ reaction, respectively. Relative efficiencies at 4 and 12 Mev also were obtained by using γ rays from the $B^{11}(p,\gamma)C^{12}$ reaction. The experimental results are within 5% of the calculated results over most of the energy range investigated. The results of this method also were compared to those obtained from the energy loss spectra for γ rays in NaI computed by the Monte Carlo method.[2] The details of the method and the results will be presented.

[1] Now at AECL, Chalk River, Canada.
[2] M. F. Miller and W. J. Snow, Rev. Sci. Instr. 31, 39 (1960).

P5. All-Electronic Precision Current Integrator.* R. J. GILLINGHAM, C. R. GILLESPIE, AND R. C. MOBLEY, *Louisiana State University.*—An all-electronic precision current integrator for use with a charged particle accelerator has been developed which eliminates the substantial deadtime normally associated with multicycle current integrators utilizing relays as their basic switching elements. Integration is accomplished in the conventional fashion of charging a precision condenser with the current to be integrated, electronically noting the completion of a predetermined voltage excursion, and then returning the condenser to its initial charge state for repetition of the cycle. A unique feature of this integrator is the return of the integrating condenser to its initial charge state through the transfer of a precise amount of negative charge to the condenser by an all electronic charge transfer circuit. Integration continues during the charge transfer with no interruption and with no affect on the precision of integration. An electronic counter circuit interrupts the integration at the end of a preset number of cycles and gates off any associated equipment.

* Supported in part by the U. S. Atomic Energy Commission.

P6. High-Energy Sodium-Iodide Spectrometer with Improved Resolution. B. ZIEGLER,* J. M. WYCKOFF, AND H. W. KOCH, *National Bureau of Standards.*—For energies above 5 Mev the resolutions of sodium-iodide total absorption spectrometers are limited by the escape of secondary photons from the surfaces of the spectrometer crystal.[1] An improved resolution has been obtained by placing a second crystal spectrometer so as to detect a single annihilation photon escaping from the front surface of the main spectrometer crystal. A coincidence requirement on this second crystal permits the selection of events in the main crystal in which (1) a pair production interaction of a primary x ray takes place close to the front face; (2) only one annihilation photon escapes; and (3) much less than 500 kev additional energy escapes from the front surface. A resolution of 2.5% was achieved for 17.6-Mev $Li^7(p,\gamma)$ rays when a main crystal 9 in. in diameter by 6.4 in. thick was used. Without the coincidence requirement a resolution of 9% was obtained. The detection efficiency for 17.6-Mev gamma rays can be made about 7%. This escape peak spectrometer will be applied to the study of nuclear absorption dips (15–25 Mev) in bremsstrahlung spectra transmitted through long absorbers.

* On leave from Max Planck Institute for Chemistry, Nuclear Physics Division, Mainz, Germany.
[1] R. S. Foote and H. W. Koch, Rev. Sci. Instr. **25**, 746 (1954).

P7. Response of Plastic Scintillator to X Rays.* R. M. FRIEDMAN, *Lockheed Missiles and Space Division Research Laboratory.*—The response of plastic scintillators to fluorescent x rays ranging in energy from 1.5 kev to 18 kev has been measured. A relative efficiency was obtained by measuring current output with scintillators mounted on both an FW-114 photodiode and a multiplier phototube. The beam was monitored in the appropriate energy ranges with either a proportional counter or a NaI counter. The results indicate a nonlinearity in response with the output per unit energy, decreasing as one goes to softer photon energy. By using a 6810-A, pulse height, distributions were obtained for energies down to 4.5 kev. The results were fitted with Poisson distributions yielding the average number of photoelectrons emitted from the photocathode per photon absorbed in the plastic scintillator. For the particular phototube used, the results indicate about one photoelectron emitted per 3 kev of photon energy absorbed. This conversion efficiency will be compared to that obtained from thin NaI and CsI crystals.

* Supported jointly by the Lockheed General Research Program and the U. S. Air Force Special Weapons Center, Kirtland Air Force Base, New Mexico.

P8. Solid State Counters for *dE/dx* and Total Energy Measurement at Cyclotron Energies.* J. T. HEINRICH AND T. H. BRAID, *Argonne National Laboratory.*—We have made surface-barrier detectors by evaporating gold onto *n*-type silicon. Detectors of 1 cm^2 sensitive area have back currents of a few tenths of a microampere at a back bias of several hundred volts. With a charge-sensitive transistor preamplifier due to Higginbotham *et al.* such detectors have given a resolution width of 60 kev when used to detect α particles from natural sources. Counters of 200 ohm-cm silicon have been reduced to uniform thicknesses of 0.002 to 0.003 in. for dE/dx measurements. They can be made sensitive essentially throughout their entire thickness. A resolution width of 10% has been obtained for dE/dx from 43-Mev α particles. After allowance for noise pickup, this agrees well with a value of 7% predicted by the simple theory of the fluctuation in the energy loss. Detectors made from 3000 ohm-cm silicon can be biased to 600 v; the thickness of the sensitive region then approaches 1 mm. The response of a dE/dx, E pair in use by the cyclotron group is linear up to the maximum available α-particle energy, 43 Mev. The resolution width observed, 1.1%, is believed to be limited by the energy spread of the beam and is much better than can be obtained from scintillation detectors.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

P9. Outer Shell Corrections for Stopping Power.* HANS BICHSEL, *University of Southern California.*—A number of stopping power tables incorporating outer shell $(M,N,\cdots)$ corrections have been computed and compared with experimental values of the stopping power of Cu, Ag, and Au. This allows the determination of I values and the four parameters given below. The M shell correction is chosen to be $C_M=[\alpha][n_M/n_L][C_L(u)]$ with $u=(\beta^2 I_L)/(\gamma I_M)$, where n_M and n_L are the numbers of electrons in the respective shells, C_L is the L-shell correction, β the velocity of the incoming particle, and I_L and I_M the average ionization potential for each shell. α and γ are adjustable parameters necessary to take care of the fact that the averaging process for I_M and I_L is not well established. C_M is thus assumed to be similar in functional dependence to C_L. For C_N a corresponding equation is chosen, requiring two parameters, α_N and γ_N. Agreement within the experimental errors, but no better than ½%, has been found between experimental data and computed tables for energies between 1 and 700 Mev for a large number of elements, using the parameters determined for Au, Ag, and Cu, and the I values necessary are 770, 485, and 320 ev, respectively. This approach therefore seems to resolve the discrepancy between high- and low-energy measurements, and it also points out the necessity for further accurate measurements of the energy dependence of stopping power over a wide range.

* Supported in part by the U. S. Atomic Energy Commission.

FRIDAY AFTERNOON AT 2:00

Statler-Hilton, Terrace Ballroom West

(J. MARION presiding)

Nuclear Reactions III

Q1. Anisotropy of the Gamma Radiation from the Proton Bombardment of K^{41}.* R. D. SHARP, L. F. CHASE, JR., E. K. WARBURTON, AND R. M. FRIEDMAN, *Lockheed Missiles and Space Research Laboratory.*—Measurements of the anisotropy of the 0.98 and 2.16-Mev gamma rays, arising from the $K^{41}(pp'\gamma)$ and $K^{41}(p\alpha\gamma)$ reactions, respectively, have been made over the regions of bombarding energy between 2.5 and 3.5 Mev containing the most pronounced structure in the previously reported excitation curves.[1] No significant deviation from isotropy for either gamma ray is observed. A comparison is made with the theoretically expected anisotropies calculated under the assumption of isolated compound states, with only the lowest allowable orbital angular momenta entering. Those compound states were chosen which would lead to

penetrabilities within an order of magnitude of the most favored situation. The consequence of the breakdown of these assumptions will be discussed. Restrictions on the spins of the compound states in Ca^{42} in a region of excitation around 13 Mev are obtained from the 2.16-Mev gamma ray, which originates from a level of known spin (2+) in A^{38}. The most likely assignment for the 0.98-Mev state is determined to be $\frac{1}{2}$, in agreement with the theoretical $\frac{1}{2}$+ prediction of Pandya.[2]

* Supported by the joint program of the U. S. Atomic Energy Commission and the Lockheed General Research Program.
[1] R. D. Sharp, R. M. Friedman, and L. F. Chase, Jr., Bull. Am. Phys. Soc. Ser. II, 4, 366 (1959).
[2] S. P. Pandya, Progr. Theoret. Phys. (Kyoto) 19, No. 4 (April, 1958).

Q2. Nuclear Resonant Absorption of Gamma Rays by Ca^{40}. A. C. ECKERT AND E. F. SHRADER, *Case Institute of Technology.*—It has been demonstrated recently that nuclear resonant absorption of gamma radiation is a useful technique for measuring total and partial widths of nuclear levels. This technique is, however, limited in application requiring strong ground-state transitions as well as stable target and product nuclei. In addition to those cases already reported, nuclear resonant absorption has been employed in this laboratory to determine the total width Γ, the radiation width Γ_γ, and the proton width Γ_p for a previously unreported level at 10.3 Mev in Ca^{40}. This level is excited by proton capture of K^{39} at a proton energy of $Ep=2.05$ Mev. The ground-state radiation has been absorbed resonantly by CaO absorbers of two different thicknesses and by Ca metal of three different thicknesses. The analysis of the absorption areas were analyzed with the aid of curves prepared by the BNL fast-chopper group for analyzing similar neutron transmission measurements for neutron parameters. Analysis of the data for the five absorber thicknesses indicate the following values for the widths of the level: $\Gamma=10.3\pm1.7$ ev; $\Gamma_p=5.8\pm1.8$ ev; $\Gamma_{\gamma 0}=3.6\pm0.24$ ev, where it has been assumed that $J=2$, which is consistent with a yield measurement.

* Work supported in part by the U. S. Atomic Energy Commission.

Q3. Gamma Radiation from the $K^{39}(p,\gamma)Ca^{40}$ Reaction.* R. L. ZIMMERMAN AND M. K. MOE, *Case Institute of Technology.*—More than sixteen previously unknown excited states of Ca^{40} have been investigated with protons of energies up to 3 Mev incident on K^{39}. In addition, work in this laboratory has resolved two closely spaced resonances near 1.566-Mev proton energy previously reported as one resonance in the literature.[1] Angular distributions were taken to supplement the resonance absorption measurement,[2] both of which bear on the proper assignment of parameters of individual excited states. The targets were prepared in several chemical forms to aid in the correct identification of resonances in the $K^{39}(p,\gamma)Ca^{40}$ reaction. The separated isotope K^{41} was studied to identify the excited states of Ca^{42} which might occur from K^{41} in targets prepared from naturally abundant potassium.

* Work supported in part by the U. S. Atomic Energy Commission.
[1] R. Berenbaum and J. H. Matthews, Proc. Roy. Soc. (London) A70, 445 (1957).
[2] See preceding abstract.

Q4. Levels of Cr^{52} from the $(n,n'\gamma)$ Reaction.* D. M. VAN PATTER, *Bartol Research Foundation.*—An attempt has been made to use the $(n,n'\gamma)$ reaction as a nuclear spectrographic tool to study levels of Cr^{52}, particularly those at 2.65, 2.77, 2.96, and 3.16 Mev,[1] for which no information regarding spin assignments was available. Observations of $(n,n'\gamma)$ spectra from natural Cr at $\theta=100°$ have been extended to $E_n=3.3$ Mev. As was found in the case of Fe^{56}, theoretical predictions using the diffuse surface potential of Beyster *et al.* are in better agreement with the observed cross section for the first 2+ level than those using the potential of Emmerich.[2] Similarly, the experimental cross section for the first 4+ level is lower than predicted; however, no correction for $(n,n'\gamma)$ angular distributions has been made. The following spin assignments give best agreement with theory: 2.65 Mev (0); 2.77 Mev ($\geq$4); 2.96 Mev (2); 3.16 Mev (1,2,3). The results clearly indicate that the lowest lying state which can be the second 2+ level is the 2.96-Mev state, which decays primarily by a cascade γ ray of 1.53 ± 0.01 Mev (crossover/cascade ≤0.03) and which is strongly excited in the (p,p') reaction at $E_p=6.5$[1] and 8 Mev.

* Assisted by the U. S. Atomic Energy Commission.
[1] M. Mazari, W. W. Buechner, and A. Sperduto, Phys. Rev. 107, 1383 (1957).
[2] For a more complete discussion see D. M. Van Patter and R. W. Jackiw, *Proceedings of the International Conference on Nuclear Structure* (1960), p. 244

Q5. Determination of (p,n) Thresholds for Cr^{52}.* J. A. BECKER AND J. D. FOX, *Florida State University.*—We have determined the thresholds for $Cr^{52}(p,n)Mn^{52}$ (5.6-day) and $Cr^{52}(p,n)Mn^{52m}$ (21-min) using the method of residual activities. The activity produced in thick Cr_2O_3 targets is detected using a 3-in. by 3-in. NaI(Tl) scintillation spectrometer. The known gamma rays and coincidence sum peaks for the decays were observed. Preliminary data show the 21-min threshold to be at 5.98 ± 0.02 Mev, in agreement with radioactivity data,[1] and in disagreement with a previous threshold measurement.[2]

* Supported in part by the U. S. Air Force Office of Scientific Research.
[1] R. K. Osborne and M. Deutsch, Phys. Rev. 71, 467 (1947).
[2] A. Hemmendinger, Phys. Rev. 58, 929 (1940).

Q6. Single-Particle Neutron Bound States near $N=28$ Studied with (p,d) Reactions. I. J. B. BALL, C. D. GOODMAN, AND C. B. FULMER, *Oak Ridge National Laboratory.**—Deuteron spectra from (p,d) reactions of 22-Mev protons on Fe^{54}, Fe^{56}, Fe^{57}, Fe^{58}, and Co^{59} have been measured experimentally. Two distinct shapes of angular distributions are observed for the deuteron groups; none of the angular distributions differs appreciably from these shapes. Although they cannot be regarded as good Butler curves, the positions of the primary maxima agree with $l=1$ and $l=3$ Butler curves approximately. The $l=1$ shape peaks at about 10 deg and the $l=3$ shape at about 30 deg. We assume that the two kinds of angular distributions correspond to angular momentum changes of one and three units, respectively, and classify the state accordingly. We find agreement with those spin and parity assignments which are known from other work. Within each class of levels, i.e., $l=1$ and $l=3$, the relative reduced widths vary by an order of magnitude. If we single out the strong peaks, we can discern a systematic shifting of the energy from isotope to isotope. For example, a strong $l=3$ peak which we assign to the pickup of an $f_{7/2}$ neutron appears at $Q=-11.2$, -10.4, -10, and -11.2 for the even neutron targets Fe^{54}, Fe^{56}, Fe^{58}, and Co^{59}, respectively. For Fe^{57} the peak is double at $Q=-9.4$ and -10.

* Operated for the U. S. Atomic Energy Commission by Union Carbide Corporation.

Q7. Single-Particle Neutron Bound States near $N=28$ Studied with (p,d) Reactions. II. C. D. GOODMAN, J. B. BALL, AND C. B. FULMER, *Oak Ridge National Laboratory.**—We attempt to interpret the strong peaks in the (p,d) spectra described in the preceding abstract in terms of single-particle neutron bound states. We take the point of view that the Q values are a measure of the binding energies of these single-particle states in the target nucleus.[1] From the number and behavior of the individual states we observe, it becomes apparent that the single-particle shell model of Mayer and Jensen, without residual interactions, is inadequate. For example, Fe^{58} may be regarded as an Fe^{54} core plus two neutrons. However, the behavior of the $l=3$ level indicates a strong influence of the two neutrons on the core. Also in Fe^{58} the 31st and 32nd neutrons do not fill the same shell as the 29th and 30th. All of the strongly excited levels and their

behavior can be understood if we assume the neutron bound states are those in a spheroidal potential as calculated, for example, by Nilsson. We consider only the single-particle aspects of the model and neglect the rotational aspects. We also assume, as is plausible from the model, that Fe^{54} and Co^{59} are spherical and Fe^{56}, Fe^{57}, and Fe^{58} have a prolate deformation.

* Operated for the U. S. Atomic Energy Commission by Union Carbide Corporation.
[1] C. D. Goodman and J. B. Ball, Phys. Rev. 118, 1062 (1960); J. B. Ball and C. D. Goodman, Phys. Rev. 120, 488 (1960).

Q8. Co and Ni(p,α) Spectra at 15 and 19 Mev.* F. Paul Brady, David G. Cassel, and R. Sherr, *Princeton University.*—In previous work we found that the continuous portion of the spectra of alpha particles produced by 17.5-Mev protons in targets of intermediate elements could be described by the statistical model. The nuclear level density was found to have the form $w \sim \exp E_x/T$. Since the excitation energy E_x equals $\epsilon_0 - \epsilon$, the expression for the cross section can be written as

$$d^2\sigma(\epsilon)/d\epsilon d\Omega \sim \exp(\epsilon_0/T)[\epsilon\sigma_c(\epsilon)\exp(-\epsilon/T)].$$

The shape of this spectrum is independent of ϵ_0, the maximum α energy. Therefore, it is possible to test this form of level density by comparing the shape of the spectra at different bombarding energies. (It is not necessary to correct spectra for target thickness or nonlinearity of the detectors, since these depend only on ϵ.) Measurements of the α's at 135° from Ni and Co at 15 and 19 Mev yielded identical continuous spectra, in agreement with a constant temperature level density. For a Fermi level density, the dependence on ϵ_0 is sufficiently strong to rule out this form as a possibility.

* This work was supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.

Q9. New Levels in Ge^{70}.* P. N. Trehan, R. Rikmenspoel, and D. M. Van Patter, *Bartol Research Foundation.*—Proton bombardment of thin Ge^{70} targets at $E_p \leq 5.2$ Mev showed 0.175-, 0.67-, 1.04-, 1.71-, and 2.15-Mev (±1%) γ rays in singles spectra and 0.18-, 0.50-, 0.67-, and 1.11-Mev γ rays in coincidence with 1.04 Mev. The 1.04- and 0.175-Mev γ rays arise from known levels at 1.04 (2+) and 1.21 (0+) Mev. The prominent γ rays of 0.67 and 1.71 Mev are assigned to a new level at 1.71 Mev, which is considered as the second 2+ level, both on the basis of systematics[1] and prominence of these γ rays, with a branching ratio (crossover/cascade) = 1.7±0.1. The branching of this level to the 1.21-Mev level was found to be <3%. The 1.11-Mev γ ray seen in the coincidence spectra indicates a new level at 2.15 Mev with a branching of 0.8±0.3. Excitation curves and angular distributions for some of the prominent γ rays have been measured.

* Supported by the U. S. Air Force through the Air Force Office of Scientific Research of the Air Research and Development Command.
[1] D. M. Van Patter, Bull. Am. Phys. Soc. Ser. II, 3, 212 (1958).

Q10. Proton Strength Functions from (p,γ) Reaction Yields. G. D. Gutsche.* *U. S. Naval Research Laboratory and Catholic University of America.*—The thick-target yield of gamma rays from radiative proton capture has been measured for 16 separated isotopes in the mass region $A = 40$ to $A = 75$. The incident proton energies were in the region of 500 kev to 1500 kev but in each case did not exceed one-fifth of the S-wave barrier height for that nucleus. The gamma-ray yields were divided by a penetrability factor to obtain a "reduced yield" closely related to the proton strength function of the compound nucleus. Peaks in the "reduced yield" occurred at compound states of $A = 50$ and $A = 65$. These results are in reasonable agreement with those of Schiffer and Lee[1] obtained from (p,n) reaction cross sections.

* Present address: Science Department, U. S. Naval Academy, Annapolis, Maryland.
[1] J. P. Schiffer and L. L. Lee, Jr., Phys. Rev. 109, 2098 (1958).

Q11. Elastic Scattering Excitation Functions for $N^{14}+C^{12}$, $N^{14}+Be^9$, and $O^{16}+Be^9$. J. A. Kuehner and E. Almqvist, *Chalk River Laboratories.*—The differential excitation functions for elastic scattering of N^{14} ions from carbon and beryllium and of O^{16} ions from beryllium have been measured for c.m. angles near 90° and c.m. energies within the range ~3–15 Mev. No strong resonance structure, as observed[1] in the differential excitation functions for C^{12} on carbon, was found. In one case, however, that of N^{14} scattered from carbon, the differential cross section near 16.5-Mev c.m. exhibits a rise and then a fall by a factor ~2 within ~200 kev c.m. The N^{14} plus carbon data show, as well, the diffraction structure characteristic of many elastic scattering data. In contrast the N^{14} plus beryllium and O^{16} plus beryllium data do not exhibit this diffraction structure. The $\eta = Z_1 Z_2 e^2/\hbar v$ values for these measurements range from ~6.2 to ~3.2 in the energy ranges employed; these data thus appear to be exceptions to the rule[2] that this diffraction structure appears whenever η is less than 5. This lack of structure may reflect a more diffuse surface for Be^9.

[1] D. A. Bromley, J. A. Kuehner, and E. Almqvist, Phys. Rev. Letters 4, 365 (1960).
[2] J. A. McIntyre, S. D. Baker, and T. L. Watts, Phys. Rev. 116, 1212 (1959).

Q12. Protons from N^{14} Bombardment of F^{19}. C. E. Hunting, *Oak Ridge National Laboratory.*—Energy spectra of protons from N^{14} bombardment of F^{19} have been observed at laboratory beam energies of 21.4 and 27.4 Mev. The laboratory angles of observation were from 20° to 140° at the lower energy and from 0° to 140° at the higher energy. The observed spectra were transformed into the c.m. system of the initial collision. When interpreted in terms of the two-body breakup reaction $F^{19}(N^{14},p)P^{28}$, these spectra were consistent with statistical model parameters which were very nearly independent of bombarding energy at a given c.m. angle. From these continuous spectra there also were obtained absolute differential cross sections for protons of fixed kinetic energy in the c.m. system, the greater anisotropy appearing at the higher bombarding energy and at the higher proton kinetic energies. Again assuming the two-body breakup reaction, in order to use a calculation of the angular momentum effect in compound nucleus processes,[1] the observed differential cross sections at the 21.4-Mev bombarding energy exhibited approximate agreement with $\sigma = 3$ in the nuclear level spin distribution $(2j+1)\exp[-j(j+1)/(2\sigma^2)]$.

[1] T. Ericson and V. Strutinski, Nuclear Phys. 8, 284 (1958).

Q13. Good Resolution Studies of Energy Spectra from (d,d') Reactions in Heavy Elements.* B. L. Cohen and R. E. Price, *University of Pittsburgh.*—Energy spectra of deuterons from (d,d') reactions induced by 15-Mev deuterons were measured with ~80-kev resolution for ~30 nuclei with masses 50–200. States known to be excited in Coulomb excitation are strongly excited here, and the cross sections for the two reactions are positively correlated. In general, the region of the anomalous peak[1] has 2 or 3 strongly excited levels, but, when the resolution is smeared out to 400 kev, there is a single broad peak with energy and cross section varying smoothly with A. In the seven most abundant isotopes of tin, there is only a single strongly excited level in the "anomalous" peak; in Sn^{116} and Sn^{124}, its angular distribution is out of phase with that of 2^+ first excited state, which indicates that its parity is negative, in agreement with collective theories. A similar situation is found in zirconium. The general correlation between cross sections for exciting given levels by (d,d') and (d,p) reaction is $\gtrsim 0$, but the levels corresponding to the collective 2^+ and 3^- states in the tin isotopes [i.e., strongly excited in (d,d')] also are fairly strongly excited in (d,p) reactions.

* Work assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] B. L. Cohen, Phys. Rev. 105, 1549 (1957).

Q14. Survey of (d,α) Reactions in Heavy Nuclei.* JAMES B. MEAD AND B. L. COHEN, *University of Pittsburgh.*—Low resolution energy spectra for (d,α) reactions initiated by 15-Mev deuterons were studied for 26 nuclei between $Z=28$ and 83. Energy distributions were obtained at scattering angles of 30°, 60°, 90°, and 120° using a scintillator-proportional counter telescope and a 256-channel analyzer. Two strong groups are found which vary regularly in cross section and peak energy with Z and show little or no energy variation with scattering angle. The angular variation of the cross section for the low-energy group is essentially isotropic and can be identified with a compound nucleus (CN) mechanism. Level density parameters $[\omega(E)\sim\exp 2(aE)^{\frac{1}{2}}]$ extracted for 7 nuclei between $Z=28$ and 46 suggest clustering about the constant value $a=6$ Mev^{-1}. The variation of observed cross sections with Z is consistant with statistical theory and constant a. Observed CN cross sections vary with Q values in the manner predicted by statistical theory. The high-energy group shows strong forward peaking in the angular distributions and is associated with a direct interaction (DI) process. Ground states of residual nuclei are weakly excited; possible reaction mechanisms for the high-energy group will be discussed.

* Work done in the Sarah Mellon Scaife Radiation Laboratory and assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

FRIDAY AFTERNOON AT 2:00

New Yorker, New Orleans Room

(N. BENCZER-KOLLER presiding)

Beta and Gamma Spectroscopy I

QA1. Finite Bremsstrahlung Cross Section at the High-Frequency Limit.* M. F. SHEA, W. C. MILLER, AND C. E. DICK, *University of Notre Dame.*—Experimental evidence showing that the cross section at the high-frequency limit of the bremsstrahlung spectrum is finite has been obtained for a photon energy of 2.13 Mev. Monoenergetic electrons from an electrostatic generator produced thin target bremsstrahlung in a 2.48-mg/cm^2 gold foil. 2.13-Mev photons emitted in the forward 20° cone were detected by means of nuclear fluorescence of the first excited state of B^{11}. The fluorescent radiation was detected at 90° to the photon beam by a 2-in.×2-in. NaI(Tl) scintillator, and the pulse-height spectrum was recovered by a 256-channel analyzer. The number of counts in the photopeak of the pulse-height distribution is a measure of the intensity of the 2.13-Mev photons in the bremsstrahlung spectrum. By plotting the number of counts in the photopeak vs incident electron energy it is possible to obtain the shape of the 2.13-Mev isochromat. This isochromat is finite at the high-frequency limit and is nearly flat for the first 150 kev above 2.13 Mev.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

QA2. Tip of the Bremsstrahlung Spectrum. R. T. DECK, C. J. MULLIN, AND W. R. JOHNSON, *University of Notre Dame.*—The finite tip of the bremsstrahlung spectrum predicted by Fano[1] and measured by Shea, Miller, and Dick[2] is computed theoretically. The bremsstrahlung matrix element is determined by using a modification of the Sommerfeld-Maue wave function[3] for both the incident and final electron. The resulting cross section is in error by terms of $O(\alpha^2Z^2)$ but valid for any electron velocity. The expression for the cross section at the tip is integrated over all outgoing electron angles and photon angles corresponding to a forward cone of arbitrary aperature. When specialized to the case described by Shea *et al.*, $k=2.13$ Mev, $\theta_0=$ photon cone half-angle $=10°$, one obtains the result

$$d\sigma=4\pi\alpha^3Z^2r_0^2e^{-\pi\alpha Z}\{0.3+0.03\alpha Z+O[(\alpha Z)^2]\}.$$

[1] U. Fano, Phys. Rev. 116, 1156 (1959).
[2] Preceding abstract.
[3] W. R. Johnson and C. J. Mullin, Phys. Rev. 119, 1270 (1960).

QA3. Branching Ratios in the Beta Decay of N^{12} and B^{12}.* NEEL W. GLASS, ROBERT W. PETERSON, AND RONALD K. SMITH, *Los Alamos Scientific Laboratory.*—The beta decay branching ratios to the 4.43-Mev level in C^{12} have been measured in the decay of N^{12} and B^{12}. The activities were produced via the $B^{10}(He^3,n)N^{12}$ and $B^{11}(d,p)B^{12}$ reactions using 3-Mev He^3 particles and 2-Mev deuterons from the large Los Alamos Van de Graaff. The beta particles were counted by a two-stage plastic fluor detector in coincidence with the 4.43-Mev gamma rays detected by a 4-in. NaI crystal. Branching ratios of $(2.4\pm0.2)\%$ and $(1.3\pm0.1)\%$ were found in the N^{12} and B^{12} decays, respectively. The ratio of the N^{12} branching ratio to the B^{12} branching ratio was measured to be 1.84 ± 0.1. Previously measured values of the branching ratio for B^{12} are $(1.4\pm0.4)\%$ (1) and $(1.7\pm0.4)\%$ (2). By use of published values of half-lives and decay energies, it is found that ft(nitrogen)/ft(boron) $=1.22\pm0.04$ for the ground-state transition and ft(nitrogen)/ft(boron) $=0.95\pm0.06$ for the 4.43-Mev level transition.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] R. W. Kavanagh and C. A. Barnes, Phys. Rev. 112, 503 (1958).
[2] N. W. Tanner, Phil. Mag. 1, 47 (1956).

QA4. Search for $2p\rightarrow 1s$ Optical Line of Positronium.* W. R. BENNETT, JR.,† W. THOMAS, AND VERNON W. HUGHES, *Yale University,* AND C. S. WU, *Columbia University.*—A search was made for the $2p\rightarrow 1s$ optical line of positronium, which should occur at 2430 A, using a grating spectrometer (line width 4 A and effective $f=0.4$) and pulse counting techniques. Cu^{64} positron sources (up to 5 C) were used, and the positrons were stopped in high purity A and Ne gas samples at pressures from 150 to 1000 mm of Hg. Getterable impurities were maintained below 1 ppm and monitored through nitrogen band intensities. Detection of the 2430 A line was limited by a continuous photon background in A and Ne similar to that found[1] with α-particle excitation in the heavier noble gases. The ratio in intensity of the background continuum (A to Ne) was $\cong 3:1$. The only structure encountered was an unidentified doublet at $\cong$3090 A in argon, previously observed[1] with α-particle excitation. The data indicate that less than 0.6% of the positrons stopping in the gas result in optical radiation from the $2p$ states of positronium. It is suggested that the low yield results from stepwise ionization of the $n=2$ state of positronium, facilitated by high kinetic energies of formation and an unusually large Van der Waals interaction.

* This research has been supported in part by the National Science Foundation and U. S. Atomic Energy Commission.
† Present address: Bell Telephone Laboratories, Murray Hill, New Jersey.
[1] W. R. Bennett, Jr., U. S. Atomic Energy Commission Rept. CU-195 (May, 1959).

QA5. Longitudinal Polarization of Positrons from Neon-19.* J. V. JOVANOVICH, E. D. LAMBE, T. A. POND, AND J. B. REYNOLDS, *Washington University.*—The longitudinal polarization of neon-19 positrons is measured by transmitting the annihilation-in-flight gamma rays through magnetized iron. The experimental method previously described[1] is unchanged except for the detectors and the associated electronics. In the new experiment two 3-in. by 3-in. NaI crystals and 50-channel pulse-height analyzers are used to measure the energy dependence of the circular polarization of gamma rays from which the energy dependence of positron polarization is inferred. The experimental asymmetries vary from zero to about 3% depending on the measured pulse-height range. The method will be described and results compared with the prediction of the two-component neutrino theory.

* Supported in part by the National Science Foundation, the U. S. Air Force Office of Scientific Research, and the Research Corporation.
[1] E. D. Lambe, J. B. Reynolds, J. Jovanovich, and T. A. Pond, Bull. Am. Phys. Soc. Ser. II, **4**, 77 (1959).

QA6. Beta Spectra of Co^{56}.* L. M. LANGER, *Indiana University*, J. H. HAMILTON, *Vanderbilt University*, AND D. R. SMITH, *Indiana University.*—The 1.46-Mev positron group in the Co^{56} decay has a log*ft* of 8.7[1] and exhibits a strong β-γ directional correlation[2] ($A_{max} \simeq 3\%$). Both these quantities are unusually large and suggest that higher order terms are contributing. The shape of the 1.46-Mev positron group was investigated carefully in detail with a 180°, shaped-field, magnetic spectrometer. Two positron groups were observed with maximum energies of 1.464 and 0.470 Mev. No evidence for another group was found; in particular, an upper limit of 1% was set for a previously reported group with maximum energy of about 1 Mev. The high-energy spectrum above 470 kev is essentially allowed; however, the data are better fitted with an empirical shape factor $(1+0.25/W)$ which has been found to be necessary in fitting other well-measured spectra.

* Supported in part by the joint programs of the Office of Naval Research and the U. S. Atomic Energy Commission and by grants from the National Science Foundation and Research Corporation.
[1] P. Kienle and R. E. Segel, Phys. Rev. 114, 1554 (1959).
[2] J. H. Hamilton, B-G Pettersson, and J. Thun, Bull. Am. Phys. Soc. Ser. II, 5, 10 (1960).

QA7. Absolute *E2* Conversion Coefficients.* J. H. HAMILTON, W. F. FREY, S. HULTBERG, AND T. DUNCAN, *Vanderbilt University.*—New evidences for discrepancies between theory and experiment in pure *E2* conversion coefficients have been reported recently.[1,2] Additional accurate *E2* conversion coefficients are needed to determine the nature of these deviations. The conversion coefficients of pure $(2+ \rightarrow 0+)$, unhindered, *E2* transitions in the decays of Ir^{192} and Eu^{152} have been measured (see Table I). These results from preliminary calculations support earlier work.[2] The internal-external method of Hultberg and Stockendal was used in an iron-free, double-focusing spectrometer.

TABLE I.

	Energy	$\epsilon \times 10^4_{exp}$	$\alpha_2 \times 10^4_{theory}$
Pt^{192}	317	440±30	545
	613	109± 8	120
Gd^{152}	344	281±20	310

* Supported in part by a grant from the National Science Foundation.
[1] DeVries and Bleeker, Nuclear Phys. 18, 454 (1960).
[2] J. H. Hamilton, W. F. Frey, and S. Hultberg, Bull. Am. Phys. Soc. Ser. II, 5, 448, 449 (1960).

QA8. Decay of the Zn^{71} Isomers.* T. T. THWAITES AND W. W. PRATT, *Pennsylvania State University.*—The Zn^{71} isomers have been reinvestigated using scintillation counter techniques. Samples enriched to 59% Zn^{70} were exposed in the P.S.U. Research Reactor. The 2.55-min isomer was found to beta decay to states in Ga^{71} yielding gamma rays of 0.12, 0.39, 0.51, 0.68, 0.92, and 1.12 Mev with intensities of 7, 10, 100, ≤ 2, 24, and 10% relative to the 0.51-Mev gamma ray. The 0.39- and 0.68-Mev gamma rays have not been reported previously. Coincidences were found between the 0.12 to 0.39-, 0.51 to 1.12-, and 0.68 to 0.92-Mev gamma rays. The 4.0-hr isomer also beta decays to a state in Ga^{71}, yielding gamma rays of 0.39, 0.49, and 0.61 Mev, all of approximately equal intensity. Beta spectra in coincidence with the 3 gamma rays were measured and all found to have the same end point of 1.46 Mev. No isomeric transition has been observed. A level scheme for Ga^{71} is proposed.

* Supported in part by the U. S. Atomic Energy Commission and the National Science Foundation.

QA9. Gamma-Gamma Directional Correlation in Mo^{94}. H. BERNSTEIN AND H. H. FORSTER, *University of Southern California.*—The directional correlation of the 700-kev to 874-kev gamma-gamma cascade in Mo^{94} has been studied with a scintillation crystal spectrometer, using two $1\frac{1}{2}$-in.$\times 1\frac{1}{2}$-in. thallium activated sodium iodide crystals and a fast-slow coincidence circuit of 14 mμsec resolving time. The radioactive source material was Nb^{94} (1.8×10^4*y*) obtained by exposing niobium pentoxide powder to the neutron flux of the Oak Ridge pile for a period of 3 weeks. Experiments were begun several months after exposure to allow for the decay of Nb^{95}(35*d*). Thin uniform sources were prepared by dissolving Nb_2O_5 in concentrated hydrofluoric acid at a temperature of 100°C and then depositing the source material onto films of Tygon or polyethylene. The experimental data gave for the Legendre polynomial expansion coefficients: $A_2 = 0.086 \pm 0.008$ and $A_4 = 0.024 \pm 0.012$, thus favoring a 2-2-0 assignment with dipole-quadrupole mixing in the first transition. The quadrupole content for this transition has been determined as $4.4 \pm 0.4\%$. A cross-over transition from the 1.57-Mev state to the ground state has been observed, substantiating this assignment.

QA10. Low-Energy Conversion Electrons of Ag^{106}. W. G. SMITH, *Purdue University.**—The internal conversion electrons emitted in the electron capture decay of the long-lived isomer of Ag^{106}, $t_{\frac{1}{2}} = 8.4_6 \pm 0.1$ days, have been investigated with the use of two permanent magnet spectrographs. The maximum electron energy that could be recorded was 940 kev. The following transitions were observed (the relative *K*-conversion electron intensities, where measurable, are shown in parentheses after the electron energy): 110.1 (12), 166.8, 195.0 (34), 221.5 (433, $K/L = 8\frac{1}{2}$), 228.6 (46), 282.0, 328.1 (52), 374.4, 390.7 (63), 396.5, 405.8 (173), 418.5, 429.6 (160), 450.6 (90), 457.3, 474.3, 511.6 (567, $K/L = 8\frac{1}{2}$), 585.7, 600.9, 615.6 (94), 679.8, 702.6, 717.1 (79), 737.6, 747.2 (24), 780.2, 792.1, 802.8 (20), 807.1, and 823.4 (33) kev. The many gamma radiations emitted in the decay of Ag^{106} recently have been studied using single, coincidence, and angular correlation scintillation techniques by Robinson, *et al.*[1] A Pd^{106} level scheme based on the present conversion electron study and the gamma-ray results will be presented.

* Work supported in part by the U. S. Atomic Energy Commission.
[1] R. L. Robinson, F. K. McGowan, and W. G. Smith, Phys. Rev. 119, 1692 (1960).

QA11. Levels of Sn^{118} from the Decay of 5-hr Sb^{118}.* H. H. BOLOTIN AND A. SCHWARZSCHILD, *Brookhaven National Laboratory.*—Investigations of the states of Sn^{118} populated by electron capture from the ground state of Sb^{118} have been carried out using scintillation techniques. Four gamma rays with energies 0.04, 0.26, 1.0, and 1.2 Mev were observed[1] and are in cascade. The γ-γ angular correlation of the 1.0- to 1.2-Mev cascade was measured, yielding a coefficient of $P_2(\cos\theta)$ of 0.104 ± 0.007 and a negligible $P_4(\cos\theta)$ term. This is consistent with a 4(2)2(2)0 cascade with no mixing, in dis-

agreement with the previously reported correlation.[2] Delayed coincidence studies indicate that the 0.04-, 1.0-, and 1.2-Mev γ rays are delayed with respect to the 0.26-Mev transition with a half-life of (20 ± 4) nanosec. The time order of the γ rays in the cascade is 0.26, 0.04, 1.0, and 1.2 Mev with the half-life assigned to the 0.04-Mev transition. This order is in disagreement with the previously reported decay scheme.[1,2] Other details of the decay scheme will be presented.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] *Nuclear Data Sheets*, C. L. McGinis, editor (National Academy of Sciences—National Research Council); C. L. McGinnis and D. N. Kundu, Bull. Am. Phys. Soc. Ser. II, 3, 62 (1958).

[2] Ramaswamy *et al.*, *Proceedings of the International Conference on Nuclear Structure* (University of Toronto Press, 1960), p. 643.

QA12. Recoilless Gamma Emission from Sn^{119m} Diffused into Iron.* O. C. KISTNER AND J. B. SWAN,† *Brookhaven National Laboratory.*—The hyperfine structure of the 24-kev γ radiation from Sn^{119m} was measured[1] using recoilless emission from a source of Sn^{119m} diffused into an iron foil. The absorber used was grey tin metal which was kept at $\sim$10°C, just below its transition temperature. Six well-resolved resonance lines were observed at relative velocities corresponding to an internal field at the Sn^{119} nucleus of approximately 80 koe. It was found possible to align the internal fields by applying an external magnetic field to the iron foil. The relative intensities of the different components of the velocity spectrum then could be decreased or enhanced by observing the γ radiation either parallel or perpendicular to the direction of magnetization, thereby allowing a more precise determination of the hyperfine splitting parameters.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

† On leave from the University of Western Australia.

[1] An earlier measurement has been made using a tin metal source and a ferromagnetic Mn_2Sn absorber by S. S. Hanna, L. Meyer-Schützmeister, R. S. Preston, and D. H. Vincent, Phys. Rev. 120, 2211 (1960).

QA13. β-γ Circular Polarization Correlation of Sb^{124}.* P. ALEXANDER AND R. M. STEFFEN, *Purdue University.*—The angular distribution of the circularly polarized 603-kev γ radiation following the 2.31-Mev $\beta-$ transition of Sb^{124} ($3^-\!-\!2^+\!-\!0^+$ cascade) has been measured. The degree of circular polarization P_c was determined for seven angles θ between 90° and 180° using very narrow γ acceptance apertures in the polarization analyzer magnet. $P_c(\theta)$ was found to be positive over this angular interval in contrast to the results of Hartwig and Schopper[1] who reported a change of sign of $P_c(\theta)$ between $\theta=90°$ and $\theta=180°$. From the measured circular polarization correlation and the β-γ directional correlation[2] the nuclear matrix elements contributing to the first forbidden 2.31-Mev $\beta-$ transition of Sb^{124} may be determined. By using Kotani's[3] notation ($z=1$) we find $Y=0.60\pm0.15$, $|u|=0.01\pm0.01$, $|x|=0.07\pm0.09$. A more accurate evaluation of the β-γ correlation results by means of an electronic computer is in progress.

* Work supported by the U. S. Atomic Energy Commission.

[1] G. Hartwig and H. Schopper, Phys. Rev. Letters 4, 293 (1960).

[2] R. M. Steffen, Phys. Rev. Letters 4, 290 (1960).

[3] T. Kotani, Phys. Rev. 114, 795 (1959).

FRIDAY AFTERNOON AT 2:00

New Yorker, Terrace Room

(BRUNO ROSSI presiding)

Cosmic Rays

R1. Soft Gamma Background Radiation at and near the Surface of the Earth.* ROGER J. HANSON, *Grinnell College.*—An outdoor background rate of $\sim$4000 counts/min is obtained with an unshielded scintillation counter employing a 1-in.$\times$1½-in. NaI(Tl) crystal. The indoor rate is about 20%–30% lower. The rate is more than two orders of magnitude greater than the cosmic-ray μ-meson rate. There is a broad peak in the energy distribution between 50 kev and 70 kev outdoors and at a slightly higher energy indoors. The width at half-maximum is about 100 kev. The rate at 500 ft above the earth's surface is reduced by a factor of two and at 2000 ft by a factor of five. It is constant from about 2000 to 8000 ft. At higher altitudes there is a steady increase. The ground-level radiation appears to be mainly due to degraded gamma radiation from radioactive substances in the earth and in building materials. At altitudes above 2000 ft, most of the gamma background is probably degraded cosmic radiation. The peak in the energy distribution is interpreted as the result of the combined effect of Compton and photoelectric interactions of the gamma rays.

* Supported by the National Science Foundation and the Research Corporation.

R2. Anomalous Abundances of Atmospheric Xenon Relative to Meteoritic Xenon Isotopes.* A. G. W. CAMERON, *Chalk River Laboratories.*—It has been found (chiefly by J. H. Reynolds) that the isotopic composition of cosmogenic xenon extracted from stone meteorites is the same except for variations in Xe^{129} (attributed to the decay of I^{129}). However, the relative isotopic composition of atmospheric xenon differs from that of meteoritic xenon in *all* isotopes. The largest difference is the excess of unshielded xenon isotopes in the atmosphere, attributed by Kuroda to spontaneous fission of Pu^{244} in the primitive earth. The differences in abundances of the shielded isotopes appear to require the subjection of part of the atmospheric xenon to a large moderated neutron flux. The order of magnitude of the anomalies can be accounted for if it is assumed that about 10% of atmospheric xenon has come from the sun where it has been subjected to the neutron flux associated with deuterium thermonuclear reactions. The ordinary constituents of the solar wind should be deflected away by the earth's magnetic field, but the large mass-to-charge ratio of the xenon ions may allow them to be captured into the atmosphere.

* Supported by U. S. Air Force Office of Scientific Research while author was at Mt. Wilson and Palomar Observatories.

R3. Interpretation of the Concentrations of Cosmogenic Rare Gases Found in Some Iron Meteorites.* PETER SIGNER AND ALFRED O. NIER, *University of Minnesota.*—The authors[1] have proposed a model giving the relative concentration of cosmogenic Ar, Ne, and He in iron meteorites as a function of the position in and size of the meteorite. In the iron meteorites Casas Grandes and Carbo, previously investigated for He^3 and He^4 variations,[2–4] the depth variation of all the isotopes of the cosmogenic rare gases has been investigated and the results found to agree with the prediction of the model. In addition, individual samples from over 10 different meteorites were

investigated. By assuming validity of the model, one can draw conclusions as to the position of the samples in the originally irradiated bodies, their size, and the radiation dosage received. Results are compared with those of other investigators.

* Research supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

[1] P. Signer and A. O. Nier, J. Geophys. Research **65**, 2947 (1960).
[2] J. H. Hoffman and A. O. Nier, J. Geophys. Research **65**, 1063 (1960).
[3] J. H. Hoffman and A. O. Nier, Geochim. et Cosmochim. Acta **17**, 32 (1959).
[4] E. L. Fireman, Nature **181**, 1725 (1958).

R4. Size Spectrum and Annual Variation of Extensive Showers.* JOHN R. GREEN AND JAMES R. BARCUS, *University of New Mexico.*—Extensive air showers have been observed with a large single scintillator for a period of about 1 yr. The accumulated data lead to an integral size-spectrum of $K(\geq N) = (2.1\pm0.3)\times10^{-7}(N/10^6)^{-(1.540\pm0.008)} m^{-2}s^{-1}str^{-1}$ for showers containing from 10^5 to 10^8 particles at 1575 msl. Although the inherent statistical accuracy is high because of the large acceptance area of the scintillator, the calibration of the apparatus introduces errors that restrict the accuracy of comparison of rates over long time intervals. As a result of this limitation, it can be said only that any annual variation in the rate of occurrence of extensive air showers of the order of 10^7 particles must be less than 8%.

* Supported by the U. S. Air Force Office of Scientific Research and the National Science Foundation.

R5. Lateral Distribution of the Energy of the Soft Component of Extensive Air Showers.* JAMES R. BARCUS AND JOHN R. GREEN, *University of New Mexico.*—The multiplicity of shower particles resulting from the traversal of various thicknesses of lead and of water has been measured using two large scintillators. Under certain assumptions regarding the relative number and relative energy of the electrons and photons, the cascade theory can be used to determine the corresponding energies. The observed frequency of occurrence of a given multiplicity then can be compared with the predicted response of the scintillators to showers striking at various distances from the apparatus to show that the average energy of the soft component at the periphery of the showers is of the order of 10^8 ev and increases to more than 10^9 ev within a meter of the shower axis. Measurements of the transition effect in water indicate that the ratio of photons to electrons is approximately unity but that the photons carry more energy at distances of 10 m and beyond than do the electrons. The measurements were made for showers of 10^5 to 10^8 particles; no effects due to size were observed.

* Supported by the U. S. Air Force Office of Scientific Research and the National Science Foundation.

R6. Cosmic Rays in 1959 and 1960.* HUGH R. ANDERSON AND H. V. NEHER, *California Institute of Technology.*—In continuation of our program of following the solar cycle change in cosmic rays near the north geomagnetic pole, we are here reporting on the results of balloon flights with ionization chambers during the summers of 1959 and 1960. During a 3-week period in 1959 at Thule, the cosmic-ray intensity was very constant and remained close to the level of 1958 with the maximum to the ionization-depth curve occurring at 250 ions cm^{-3} sec^{-1} atm^{-1} of air. During a 17-day period in 1960 the average intensity was higher, namely, some 14%, or about 288 in the same units. This increase in in line with that expected from a general decrease in solar activity. These last two years' observations, combined with those of previous years, allow an estimate to be made of the phase between cosmic-ray intensity and solar activity. It now appears that there is about a 6-month lag between the average solar activity and the corresponding change in the average level of cosmic-ray intensity.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

R7. Asymmetry in the Recovery from a Very Deep Forbush-Type Decrease in Cosmic-Ray Intensity. SERGE M. LAPOINTE, *Université de Montréal,* AND D. C. ROSE, *National Research Council.*—The intensity-time curves for cosmic rays recorded at some thirty stations distributed all over the world are examined for structure in the recovery period from the third in a series of three closely spaced Forbush-type decreases which occurred in the middle of July, 1959. It is shown that the structure of intensity peaks is regular and that these occur at each station at the same effective local time, after correction is applied for the deflection of the particles in the earth's magnetic field. Evidence leading to the nature of the energy spectrum of the beam responsible for one peak is discussed. The spectrum of ordinary galactic cosmic rays gives reasonable agreement. The latter is assumed, and it is found that all this is consistent with the hypothesis that recovery from a very deep Forbush-type decrease is first apparent in directions making 15° and 165° with the sun-earth line, respectively. The analyses suggest further that, during recovery from this deep Forbush decrease, temporary openings appeared in the intensity depressing mechanism which allowed intensity increases in limited directions.

R8. On the Short-Time Fluctuations of Cosmic-Ray Intensity.* V. L. PATEL AND K. MAEDA, *University of Maryland.*—In order to resolve possible short-period variations of cosmic-ray intensity (time scale of a few minutes) high counting (approximately 40 000 per min) cosmic-ray telescopes have operated at Climax and at Banff. Fluctuations have been observed in the rate-meter records which show a strong local time dependence with a maximum near 1400 hr. This is consistent with a preliminary result of K. Tozuka and M. Wada (private communication) although their method of analysis is somewhat different from ours. Possible intrepretation of this diurnal effect as well as other nonperiodic short-time variations will be discussed. We can show that a meteorological cause is improbable.

* Supported by the U. S. Air Force Office of Scientific Research.

R9. Measurement of Gamma-Ray Fluxes in and above the Atmosphere. JOHN A. NORTHROP, *Los Alamos Scientific Laboratory,* AND ROBERT L. HOSTETLER, *Sandia Corporation.*—Two-stage sounding rockets have been used to carry phoswich gamma-ray spectrometers to an altitude of 75 miles at Tonopah, Nevada. The instrument head weighed 12 lb and the attached rocket 7½ lb. About 1.3 g/cm^2 aluminum surrounded the detector over most of the effective 4π solid angle. The 1¾-in.×1¾-in. CsI(Tl) crystal encased in a ½-in. plastic scintillator jacket was used to detect and telemeter the amplitude of individual gamma-ray scintillations (0.3 to 3.0 Mev) in the CsI and the rejection of charged particles in the plastic. The maximum flux occurs at 52 000 ft with representative integral counting rates: $E_\gamma>0.3$ Mev, 185 sec^{-1}; >0.6 Mev, 105 sec^{-1}; >1.0 Mev, 45 sec^{-1}. The flux is constant at all altitudes above 120 000 ft: 64, 32, and 11 sec^{-1} at the three biases, respectively. The charged particle counting rates (energy in the plastic >0.3 Mev) are 82 sec^{-1} at the atmospheric maximum and 38 sec^{-1} above the atmosphere. The differential spectrum above the atmosphere was examined for the presence of a 2.23-Mev peak. An upper limit for this flux from the sun is 0.5 photon/cm^2-sec.

R10. Detection of Primary Cosmic-Ray Particles in Large Silver Chloride Single Crystals.* CHARLES B. CHILDS, *Goddard Space Flight Center,* AND LAWRENCE SLIFKIN, *University of North Carolina.*—Patterns attributable to tracks of heavy cosmic rays have been developed internally in large single crystals of silver chloride. Crystals which had been flown at 120 000 ft were treated according to the procedure of Haynes and Shockley. Pulsed ultraviolet radiation produces photo-

electrons near the surface of the crystal. If the surface is sufficiently undistorted, these electrons then may be swept into the interior by a synchronous electric field. Some photoelectrons become trapped along imperfections formed by the cosmic-ray track. Silver ions combine with these electrons to form silver atoms which then serve as further traps. Ultimately the cosmic-ray track is delineated by microscopic silver specks. Preliminary investigations show several events which can be attributed to cosmic-ray particles. Possible advantages of this technique are lack of angular distortion during development and high density of the medium. We wish to thank Dr. E. Ney, University of Minnesota, Dr. M. W. Friedlander, Washington University, and Dr. C. Fichtel, Goddard Space Flight Center, for flying the crystals and treating several accompanying emulsions.

* Supported in part by Office of Ordnance Research, U. S. Army, and Office of Scientific Research, U. S. Air Force.

R11. Isotopic Composition of the Low-Energy Helium Nuclei in the Primary Cosmic Radiation.* M. V. K. Appa Rao, *University of Rochester* (introduced by M. F. Kaplon).—The isotopic composition of low-energy helium nuclei in the primary cosmic radiation has been determined by using the "Constant Sagitta" scattering method on tracks of helium nuclei stopping in a nuclear emulsion stack flown at a geomagnetic latitude $\lambda=55°$ and at a mean atmospheric depth of 8.5 g; tracks with zenith angle less than 30° were accepted. The ratio $He^3/(He^3+He^4)$ for the same energy per nucleon (between 200 and 400 Mev) is found to be 0.41 ± 0.087 at flight altitude. The correction for production of secondary He^3 in the residual atmosphere is calculated to be less than 5%. The ratio observed corresponds to a traversal of 14 ± 3 g of interstellar matter by the low-energy helium nuclei, assuming no He^3 nuclei present at the source. The value of $He^3/(He^3+He^4)$ corresponding to the same magnetic rigidity (between 4.32×10^8 and 5.33×10^8 gauss-cm) is found to be 0.36 ± 0.105 which corresponds to a traversal of 12.2 ± 3.5 g of interstellar matter. The above results and their implications will be discussed.

* This research was supported in part by the U. S. Air Force through the Office of Scientific Research, Air Research and Development Command.

R12. Nuclear Emulsion Study of a Solar Proton Beam. Carl E. Fichtel, *Goddard Space Flight Center.*—A Nike-Cajun rocket was fired into a moderate solar proton beam on September 3, 1960, at Fort Churchill, Canada. There was an absorption of 1.3 db showing on the Churchill riometer at the time of the firing, and the flux of protons greater than 15 Mev was a few hundred times cosmic-ray background. The payload containing nuclear emulsions and counter instrumentation was recovered in good condition shortly after the firing. The results of a preliminary analysis of the data obtained from the nuclear emulsions experiment will be presented. In particular, the energy spectrum for protons down to approximately 15 Mev and a general description of the composition of the beam will be given.

R13. Flux and Energy Spectra of Protons in Inner Van Allen Belt. John E. Naugle and Carl E. Fichtel, *Goddard Space Flight Center.*—Preliminary results from emulsions exposed at 2000 km in the inner Van Allen Belt will be presented. A cylindrical stack of emulsions were carried on a four-stage solid propellant research rocket inside a tungsten cassette, 27 g/cm² thick, to shield them from protons of ≤150 Mev. The emulsion stack rotated during the flight exposing different portions of the stack to the radiation through a port in the tungsten. This port was covered by 0.032 g/cm² of aluminum which constituted the only material between the emulsions and the ambient radiation. The minimum detectable energy for a proton was 7 Mev. The flux and energy spectra of protons in the energy range 7–150 Mev at 2000 km will be given.

R14. Pitch Angle Diffusion in a Magnetic Mirror Geometry.* R. C. Wentworth† and W. M. MacDonald, *University of Maryland.*—The diffusion in pitch angles produced by Coulomb collisions of charged particles in a magnetic mirror has been discussed by several authors using a variety of distribution functions and corresponding diffusion equations. A new derivation of an appropriate diffusion equation will be presented by considering the random motion of particles on a sphere in momentum space. The effect of scattering at different points of the periodic particle orbit must be considered and leads to corrections to previous results on this problem. For example, in the case of particles trapped in the earth's radiation belts, the trapped particles tend to concentrate at intermediate pitch angles away from equatorial orbits.

* This research was supported in part by the U. S. Air Force and by the Office of Naval Research.

† Present address: Lockheed Missiles and Space Division, Palo Alto, California.

Friday Afternoon at 2:00

Statler-Hilton, Terrace Ballroom East

(R. M. Bozorth presiding)

Magnetism

RA1. Investigation of the Coercive Forces of Ni, Fe, and NiFe Films during and after the Evaporation. Klaus H. Behrndt, *IBM Federal Systems Division.*—The magnetic properties of thin films and their dependence upon the amount of trapped gas and oxidation were investigated during and after the deposition in various residual gas pressures. The Magneto-Optic Kerr Effect was utilized for this evaluation. Although the penetration depth of light into the film material was determined to 150 ± 25 A, measurements of H_c could commence for film thicknesses <100 A. Studies of the coercive force during the evaporation indicated that H_c is independent of film thickness if the content of trapped gas, as indicated by the quotient d (pressure during deposition over deposition rate), is very small, i.e., of the order of 10^{-8} Torr/A/sec for Ni. The corresponding d value for Fe and NiFe seems to be lower. An explanation for this behavior is proposed. The coercive force of the films is strongly temperature-dependent. This effect, which is most pronounced for nickel, is partially caused by magnetostriction. On exposing the films to air, an increase of the coercive force is observed, which is relatively small for the films prepared at elevated substrate temperatures and very likely due to oxidation.

RA2. Magnetic Moments and Curie Temperatures of Lithium Substituted Manganese Ferrite. T. R. McGuire and S. F. Ferebee, *U. S. Naval Ordnance Laboratory.*—Divalent

manganese has been replaced by monovalent lithium in $MnFe_2O_4$. In this substitution one manganese atom becomes trivalent for each lithium atom added as given by the chemical formula $Mn_{1-2x}^{++}Mn_x^{+++}Li_x^{+}Fe_2O_4$. Compositions for $x=0.1$, 0.2, 0.3, 0.4, and 0.5 were prepared. X-ray diffraction showed that the spinel structure was formed and the unit cell lattice parameter decreased slightly from 8.51 A at $x=0.1$ to 8.47 A at $x=0.5$. The magnetic moment per formula unit decreased with added lithium from $\mu_B=4.40$ at $x=0.1$ to $\mu_B=2.35$ at $x=0.5$. The Curie temperatures, however, increased over this same composition range from 310°C at $x=0.1$ to 420°C at $x=0.5$. This behavior may be due to additional iron atoms on A sites raising the Curie temperature, a conclusion based on the higher Curie point found for magnetite. A possible distribution for $x=0.5$ is $Fe_{0.83}Mn_{0.17}[Li_{0.5}Fe_{1.16}Mn_{0.34}]O_4$ where the ions inside the brackets are on B sites and Mn^{+++} is given a moment of $4\mu_B$.

RA3. dc Effects in Ferromagnetic Resonance of Thin Nickel Films.* W. G. EGAN AND H. J. JURETSCHKE, *Polytechnic Institute of Brooklyn.*—Ferromagnetic resonance is observed in nickel films thin compared to their skin depth by the appearance of dc electric fields, which are attributed to the Hall effect interaction of the microwave electric and magnetic fields by virtue of the precession of the magnetization.[1] Experiments were performed to test the predictions of the electromagnetic theory of this interaction.[2] All detailed features of the theory have been verified in a simple experimental arrangement in which the greatest care was taken to subject the film to controlled and known local electromagnetic fields. The theoretical interpretation of the results permits obtaining values for the surface resistivity, extraordinary Hall coefficient, and anisotropic magnetoresistivity of thin films at microwave frequencies, in addition to a sensitive determination of their saturation magnetization, relaxation time, and g value. Nickel films 90 to 700 A give values of surface resistivity larger and extraordinary Hall coefficient smaller than at dc, while the magnetoresistive anisotropy remains unchanged. The magnetic properties reveal lower saturation magnetizations but close to the relaxation time and g value of bulk nickel.

* Supported by the Office of Naval Research.
[1] H. J. Juretschke, J. Appl. Phys. **31**, 1401 (1960).
[2] W. G. Egan, Ph.D. Thesis, Polytechnic Institute of Brooklyn (1961).

RA4. Nuclear Polarization of Impurities in Ferromagnets. F. J. BLATT* AND R. J. ELLIOTT, *Clarendon Laboratory, Oxford.*—The nuclear polarization of impurities in iron is estimated. The polarization, arising from the contact interaction with the polarized conduction electrons is deduced by determining the charge density and conduction electron polarization in the impurity cell. The estimates of the nuclear polarization, based on these calculations and on hfs data, agree reasonably well with recent experimental results[1] provided the conduction electrons in iron are assumed only partially s-like.

* National Science Foundation postdoctoral fellow, on leave from Michigan State University.
[1] B. N. Samoilov, V. V. Sklyarevsky, and E. P. Stepanov, J. Exptl. Theoret. Phys. (U.S.S.R.) **36**, 644 (1959); **36**, 1944 (1959); **38**, 359 (1960).

RA5. Field Dependence of the Magnetic Scattering in $CuCr_2O_4$.* R. NATHANS, *Brookhaven National Laboratory,* S. J. PICKART, *U. S. Naval Ordnance Laboratory* and *Brookhaven National Laboratory,* AND A. MILLER, *RCA Laboratories.*—Neutron diffraction investigations using an applied magnetic field have substantiated the Yafet-Kittel triangular spin configuration in $CuCr_2O_4$ proposed by Prince. No additional reflections were observed in a pattern taken at 4.2°K beyond those reported at 77°K. We find that the magnetic (111) and (220) reflections of the face-centered spinel cell, in contrast to normal behavior, *increase* upon application of a magnetic field along the scattering vector, while the (002) reflection remains unchanged. These observations imply that the Cr^{3+} moments must be nearly antiparallel to each other and perpendicular to the net magnetization of the sample, and further that they are nearly perpendicular to the tetragonal c axis. The observed increases are in reasonable agreement with a model in which the Cr^{3+} moments lie in (001) sheets with the resultant B site moment pointing either in the [100] of [010] direction. By following the magnetic intensities as a function of temperature we determine that the transition point of this spin arrangement is approximately the same as that found for the spontaneous magnetization. The specimen used in the present study was made up in the form of sintered bars to prevent particle reorientation under the application of the field.

* Carried out under the auspices of the U. S. Atomic Energy Commission.

RA6. Model for Rotational Hysteresis at High Magnetic Fields. W. H. MEIKLEJOHN, *General Electric Research Laboratory.*—Stoner and Wohlfarth have shown that, if a single domain ferromagnetic particle with a uniaxial anisotropy is rotated in a magnetic field, there will be an energy loss (rotational hysteresis) for $K/M_s<H<2K/M_s$ and no loss for other values of field. It is shown that if a ferromagnetic and ferrimagnetic system are coupled (exchange anisotropy) such that the ferromagnetic spins want to be antiparallel to the uncompensated spins, then the rotational hysteresis can be nonzero for $H>2K/M_s$. If we denote the ferromagnetic magnetization as M_1, the ferrimagnetic net magnetization as M_2, and the coupling constant as γ, then there will be rotational hysteresis for H greater than the least of the three "fields" γM_1, γM_2, and K/M_s and for H less than the greatest of the three "fields" γM_1, γM_2, and $2K/M_s$, and otherwise zero. The rotational hysteresis is relatively constant over the allowed values of H. Thus the model will yield rotational hysteresis for $H>2K/M_s$ when either $\gamma M_1>2K/M_s$ or $\gamma M_2>2K/M_s$. The hysteresis loop is parallel to the H axis for small values of H and saturates at the field where the rotational hysteresis disappears.

RA7. Application of the Thermodynamic Green's Function Formalism to Ferromagnetism. G. W. PRATT, JR., AND R. D. PUFF,* *Lincoln Laboratory.*†—A general expression is derived for the free energy of a many-electron system as a function of particle density, temperature, and total magnetization. Separate chemical potentials μ are introduced for each spin, and the free energy is a minimum when these spin-dependent μ's are equal. This condition leads to an equation for the magnetization as a function of temperature. The chemical potentials can be derived from self-consistency conditions on the thermodynamic Green's functions. The formalism has been applied to the familiar problem of a system of localized spins described by the nearest neighbor exchange Hamiltonian $\mathcal{H}=-2J\sum_{i<j}\mathbf{S}_i\cdot\mathbf{S}_j$. The first of a sequence of correlative approximations for the Green's functions leads to the Heisenberg theory. A second approximation which retains two-particle correlations between nearest neighbors gives a spectrum of excitation energies rather than the single Heisenberg made. The thermodynamic consequences of this treatment will be discussed.

* Operated with support from the U. S. Army, Navy, and Air Force.
† Now at the University of Illinois.

RA8. Green's Function Treatment of Neutron Diffraction in Anti-Ferromagnetics. DAVID G. BOULWARE,* *Lincoln Laboratory*† (introduced by G. W. Pratt, Jr.).—The neutron cross section of a collection of spins is given by the spin-spin correlation function $\langle S_i(0)S_j(t)\rangle$ where $\langle\ \rangle$ represents a thermal average. Creation operators for a cluster are introduced, and the equations for the associated Green's functions are found using an anisotropic exchange Hamiltonian. The spin-spin correlation function is given in terms of the two-particle Green's function G_2 which, along with the one-particle Green's function G_1, gives the thermodynamic function and magnetic susceptibility. A first approximation is $G_2=G_1G_1\pm G_1G_1$, which is

equivalent to the Weiss Molecular Field Theory if we consider single-spin clusters and the Oguchi or Bethe-Peierls-Weiss theories for larger clusters. Alternative methods of systematic approximation such as those discussed by Martin and Schwinger may be applied readily. As an example, the theory is applied to Cr_2O_3 with a two-ion cluster, giving results in agreement with experiment.

* Operated with support from the U. S. Army, Navy, and Air Force.
† Now at Harvard University.

RA9. Ferromagnetism of Bloch Electrons. F. ENGLERT,* *Cornell University.*—The equations of motion of spin excitations operators with wave vector $q(a^{+}_{k+q,n\downarrow}a_{k,n\uparrow})$ are studied in random phase approximation. An integral equation is derived for the elementary excitations energies, depending on the net magnetization R. Two types of excitation may occur: (a) a continuous spectrum of individual spin excitation separated from the ground state by an energy gap; (b) a bound state of collective spin-wave character which may or may not decay into the individual spin excitations, depending on the value of R. The analysis is carried out at arbitrary temperature: The collective state acquires a shorter lifetime and disappears at the Curie point where the individual spin excitations build up a self-consistent susceptibility as calculated in conventional perturbation theory. R is then determined self-consistently by the generalized Nyquist theorem as in a previous study of the Heisenberg model.[1] Thus, the magnetic and the thermodynamic properties of Bloch electrons may be computed in terms of the elementary excitations.

* On leave of absence from "Université Libre de Bruxelles."
[1] F. Englert, Phys. Rev. Letters 5, 102 (1960).

RA10. Spin Wave Spectrum at Low Temperature. R. BROUT AND F. ENGLERT, *Cornell University.*—Recently Keffer[1] and independently Herring[2] have concluded that the statement that spin-wave frequencies renormalize with the magnetization[3] is incorrect at low T. This point has been checked, and the error in the analysis of reference 3 has been found. The authors now agree with Keffer and Herring. In particular, it is found that for a Heisenberg ferromagnet, at low temperature, the spin-wave frequency at wave number $\mathbf{q}$ is given by

$$\omega(\mathbf{q}) = 2[v(0) - v(\mathbf{q})]R + 4/N \sum_{\mathbf{q}'} [v(\mathbf{q}') - v(\mathbf{q}+\mathbf{q}')]n(\mathbf{q}'),$$

where $v(\mathbf{q})$ is the Fourier transform of the exchange interaction and $n(\mathbf{q})$ is the number of spin waves at temperature T. R is the relative magnetization at temperature T. For near-neighbor interactions only, this reduces to Keffer's statement[1] that the spin waves are renormalized with the energy. In general, all that can be said is that R drops out by the sum rule $\Sigma_{\mathbf{q}}\, 2n(\mathbf{q}) = N(1-R)$.

[1] F. Keffer, Phys. Rev. (to be published).
[2] C. Herring (private communication).
[3] R. Brout and H. Haken, Bull. Am. Phys. Soc. Ser. II, 5, 148 (1960).

RA11. Spin-Wave Theory of Ferromagnetism for a Two-Dimensional Lattice.* DAVID I. PAUL, *University of California, Los Angeles.*—Some exact solutions are obtained for the Dirac spin wave Hamiltonian of a two-dimensional periodic rectangular array of N atoms. Each atom in its isolated state is considered to have one outer electron which is in an s state, all other electrons being in closed shells. We show that, if the number of spin waves is not greater than the number of atoms in either of the two lattice directions, exact solutions exist in which the spin waves behave as independent particles subject to the Pauli exclusion principle. Thus, the energy eigenvalues for these particular solutions are rigorously additive and are the same as those obtained by Bloch although the number of allowed eigenstates are more restricted.

* Supported in part by the Office of Naval Research.

RA12. High-Temperature Spin-Spin Correlation Functions in the Heisenberg Model. PETER J. WOJTOWICZ, *RCA Laboratories.*—The instantaneous scalar spin-spin correlation function γ_R (first introduced in connection with the theory of critical magnetic scattering[1]) may be defined in terms of the canonical ensemble expectation value $\langle \mathbf{S}_0 \cdot \mathbf{S}_R \rangle_T$, where $\mathbf{S}_0$ and $\mathbf{S}_R$ are the spin operators for an atom at the origin and an atom at a general lattice position Ψ, respectively. This paper is concerned with the derivation of the high-temperature behavior of γ_R for the Heisenberg model in which nearest-neighboring pairs of spins possess an interaction of the form $-2J\mathbf{S}_1 \cdot \mathbf{S}_2$. It is first demonstrated that γ_R is related to the derivative of the free energy of the spin system with respect to J_R, the strength of a *fictitious* interaction coupling $\mathbf{S}_0$ to $\mathbf{S}_R$. This result then permits the straightforward evaluation of γ_R in the form of a power series in J/kT, the coefficients of which are computed exactly for arbitrary spins and general lattices by the use of a diagram type of analysis.[2]

[1] L. Van Hove, Phys. Rev. 95, 1374 (1954); R. Elliot and W. Marshall, Revs. Modern Phys. 30, 75 (1958).
[2] G. Rushbrooke and P. Wood, Mol. Phys. 1, 257 (1958).

RA13. Theory of Relaxation Phenomena near the Second-Order Transition Point.* TOMOYASU TANAKA, PAUL H. E. MEIJER, AND JEREMIAH H. BARRY, *Catholic University of America.*—Kinetics of Ising model is discussed from the point of view of thermodynamics of irreversible processes. An expression for the entropy production when the density, the long-range order, and the short-range order are shifted from their equilibrium values is obtained from the free energy in Bethe's approximation. By introducing Onsager's reciprocal relation a set of master equations for long-range order and short-range order is obtained. The solution of the master equations gives two relaxation times which are strongly temperature-dependent functions. One of the relaxation times becomes infinity at the critical temperature, just as is predicted by Landau and Khalatnikov, but the other remains finite even at the critical temperature. A long-range constant can be defined even above the critical temperature contrary to Khalatnikov's assumption, since the sound wave will create a certain short-range order which in turn will create long-range order. In terms of these relaxation times an expression for the complex velocity of sound is obtained which gives the anomalous dispersion and absorption of sound waves near the second-order phase transition point. The attenuation at the critical point stays finite.

* Supported by a U. S. Air Force contract.

RA14. Master Equation of a Set of Weakly Coupled Ising Spins.* PAUL H. E. MEIJER, TOMOYASU TANAKA, AND JEREMIAH H. BARRY, *Catholic University of America.*—The master equation of a set of independent equivalent Ising spins contains only one undetermined constant, the rate constant. If we assume the local field to be altered by the field produced by the two neighboring spins, one can formulate a hierarchy of equations for the time dependence of the average spin $\langle \sigma_k \rangle$, the average of two neighboring spins $\langle \sigma_k \sigma_{k\pm1} \rangle$, the average of three neighboring spins, etc. This set of simultaneous linear first-order differential equations can be solved if one makes a cutoff by assuming that the local field is smaller that the external field. The two sets of equations, one for $\langle \sigma_k \rangle$ and the other for $\langle \sigma_k \sigma_{k+1} \rangle + \langle \sigma_k \sigma_{k-1} \rangle$, are solved by a Fourier transform. The resulting secular equation determined two sets of relaxation times. The initial conditions are taken in the form of a delta function in order to obtain the Green's function of the problem. The initial conditions have to be replaced by two proper linear combinations of initial conditions in order to determine the time-dependent solution. The solution has the general characteristic of a Gaussian with a variance that increases in time, but the area under the curve diminishes approximately exponentially.

* Supported by a U. S. Air Force contract.

FRIDAY AFTERNOON AT 2:00

Martinique, Empress Josephine Room

(M. RUDERMAN presiding)

Theoretical Physics V: Scattering Theory

S1. Nuclear Single-Particle Wave Functions: Application to Pion Production Theory. K. R. GREIDER AND R. THIEBERGER, *University of California, La Jolla.*—Single-particle nuclear wave functions have been developed by solving an appropriate single-particle Schroedinger equation in a Hartree-type approximation with two-body central forces. The results are expressed in analytic form in terms of the separation r of the particle from the center-of-mass of the remaining system. These wave functions yield the correct asymptotic behavior for large separation yet they are quite smooth for very small r. In particular, the functions for the very light nuclei (H^3,He^3, He^4) have been studied and yield expressions which we believe are much more accurate than those existing previously in that they predict the experimental single-particle momentum distributions quite well. Applications to the theory of meson production (with final-state alphas or tritons) by high-energy $(p+d)$ and $(d+d)$ reactions will be discussed.

S2. On the Transition Matrix for Nucleon-Nucleon Scattering.* K. L. KOWALSKI AND D. FELDMAN, *Brown University.*—As part of a study of the influence of off-the-energy-shell effects on the optical potential for nucleon-nucleus scattering, a method is presented for the calculation, via the reactance matrix, of the nucleon-nucleon transition matrix in terms of an internucleon potential and the scattering amplitude. The singular integral equations for the partial-wave amplitudes of the reactance matrix are reduced to a Fredholm form which contains the scattering amplitude parametrically. The iteration solution of these Fredholm equations is shown to be generally unreliable; however, the zeroth-order iteration approximates the exact solution quite well near the energy shell. The replacement of the kernels of these integral equations by separable functions is discussed; the validity of such an approximation is illustrated by a simple example. The requirement that the solutions of the (exact) Fredholm equations be consistent with the original singular integral equations yields a solution for the scattering amplitude in terms of the resolvent kernels of the Fredholm equations. The entire formalism is so constructed as to include the possiblity of a hard-core being present in the nucleon-nucleon interaction.

* Supported in part by the U. S. Atomic Energy Commission.

S3. Measurement of Nuclear Transitions with $\approx 10^{-20}$-sec Half-Lives and the Scattering Cross Sections of Unstable Particles by Proximity Scattering.* RAYMOND FOX, *Lawrence Radiation Laboratory, Livermore.*—Proximity scattering, as defined by the author, is a description of the following reaction. An incident particle (0) strikes a target nucleus (1), forming a composite nucleus (2) which then decomposes into two particles (3) and (4). Particle (4) at some time later decays into two particles (5) and (6), whereupon particle (5) then interacts with particle (3). A quantum mechanical study of this interaction has been made. The results indicate that the energy and angular correlation of (5) and (3) can be used to determine the half-life τ of particle (4) when the cross section for (5–3) scattering is known. This is the case when the (5–3) interaction is a proton-neutron interaction, for example, For certain relative energies of (5) and (3) the angular correlation is insensitive to τ and only dependent on the (5–3) interaction potential. Proximity scattering then indicates the possibility of obtaining the scattering cross section of unstable particles such as when the (5–3) interaction is a neutron-neutron interaction, for example.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

S4. Low-Energy Limit of Compton Scattering without T, C, P, Invariance.* E. KAZES, *The Pennsylvania State University.*—It is shown that the Compton scattering amplitude from a Fermion can be calculated uniquely in terms of charge, mass, anomalous magnetic moment, and electric dipole moment to the first two orders in the frequency, if TCP invariance alone should be valid. If either P or T invariance should exist, our result reduces to the low-energy theorem previously found.

* Supported in part by the U. S. Atomic Energy Commission.

S5. Pion-Nucleon Elastic and Inelastic Scattering in the Boundary Condition Representation. E. LOMON, *M.I.T.*—The boundary condition representation successfully used in treating the nucleon-nucleon interaction can be applied in principle to any strong interaction. The pion-nucleon interaction is a particularly simple case, and the relevance of boundary condition parameters already has been discussed by Weisskopf.[1] The method can be extended to include the effect of a potential tail and the effect of other pions in the field. These other pions are only a small perturbation below threshold for pion production. Above threshold, a coupled system of equations is obtained connecting the production cross section to the elastic cross section. Work is in progress to evaluate the parameters consistent with the broad range of elastic and inelastic data now available.

[1] Victor F. Weisskopf, Phys. Rev. 116, 1651 (1959).

S6. Electromagnetic Production of Pion Pairs. CLAYTON D. ZERBY, *Oak Ridge National Laboratory.**—The suggestion that the electromagnetic production of pion pairs may be a possible way of investigating the π-π interaction has stimulated this study of the Pauli-Weisskopf theory of pair production in the experimentally attainable region just above threshold. The pion-nucleus interaction was included in the theory in the form of a complex optical potential. It was found that the potentials could be included in the field equations in a consistent manner that would lead to the absorption and scattering of the pions if the real part of the potential was a world scalar and the imaginary part was the time component of a four-vector. The matrix element was obtained using exact waves which were expanded into angular momentum states, and numerical calculations were performed to examine the effect of a nuclear charge distribution and potential on the cross section. The calculations show that the cross section for lead with a charge distribution and nuclear optical potential increase slowly just above threshold until 295 Mev where it starts to increase almost linearly, attaining a value of 1.07×10^{-28} cm^2 at 310 Mev.

* Operated by Union Carbide Corporation for the U. S. Atomic Energy Commission.

S7. Distortion Effects in the Scattering of High-Energy Nucleons. R. M. DRISKO, R. H. BASSEL, AND G. R. SATCHLER, *Oak Ridge National Laboratory.*—The effects are studied of the elastic scattering of incident and outgoing waves during a direct-interaction inelastic scattering of high-energy nucleons. Energies of 150 and 300 Mev exciting the 4.43-Mev level in C^{12}

were considered in detail, in distorted wave Born approximation, and the differential cross sections, polarization, and γ-ray correlation parameters calculated. The distortion effects are not negligible, although the reaction retains the recoil direction as a symmetry axis, to a good approximation. At 150 Mev the cross section is considerably reduced in magnitude. Both single-particle and collective transitions were calculated, and the relative effects of distortion on the spin-flip and nonspin-flip terms studied. The exact distorted wave matrix elements are compared to those calculated in W. K. B. approximation. This work was carried out with the aid of an IBM 704 computer.

S8. Toward a Theory of High-Energy Inelastic *N-N* Collisions.* GEORGE SALZMAN AND FREDA SALZMAN, *University of Colorado.*—Increasing experimental evidence that many high-energy inelastic *N-N* collisions occur with large impact parameters suggests the importance of single pi-meson exchange graphs.[1] Application of a recently given field theoretical description of general inelastic binary collisions dominated by single boson exchange graphs[2] to these *N-N* collisions leads naturally to the two "independent" groups of final state particles that are observed. Use of the "natural" phase space variables[2] makes the problem amenable to relatively simple analysis. With the plausible assumption that the "scattering" cross sections of the exchanged "almost real" pion with the incident nucleons are close to the real cross sections at high energies, one obtains qualitative understanding of certain features observed in inelastic *N-N* scattering all the way from incident nucleon laboratory energy of 10 Bev up to and including ultrarelativistic energies.

* Supported in part by a grant from the National Science Foundation.
[1] See F. Salzman and G. Salzman "High-energy nucleon-nucleon collisions," references 1–5 (to be published).
[2] F. Salzman and G. Salzman, Phys. Rev. Letters **5**, 377 (1960).

S9. Inelastic Proton-Deuteron Scattering.*† ALAN H. CROMER, *Harvard University.*—An impulse approximation calculation has been made of the differential cross section $d^3\sigma/d\Omega dp$ for high-energy protons inelasticaly scattered from deuterium. At small angles and small energy loss the process consists mainly of events in which the target nucleons end up in a relative ^1S scattering state. The ^3S state is suppressed at forward angles because the final state wave function is orthogonal to the deuteron ground state wave function. The cross section thus depends mainly on the ^3S (deuteron ground state) to ^1S transition and provides a means of measuring the triplet-to-singlet nucleon-nucleon transition probability, given by $\Sigma_e = |B_0 - B_1|^2 + |C_0 - C_1|^2 + |E_0 - E_1|^2 + |F_0 - F_1|^2$. Here B, C, E, and F are the usual spin-dependent amplitudes in the isotopic singlet and triplet nucleon-nucleon scattering matrices. These calculations will be compared with the measurements of Stairs and Wilson[1] for 158-Mev protons.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† This work was done in part at the M. I. T. Computation Center Cambridge, Massachusetts.
[1] D. Stairs and R. Wilson, abstract U3 in this Bulletin.

S10. Rotational Inelastic Scattering at High Energies.* R. J. GLAUBER, *Harvard University.*—Let $V(r)$ be a spherically symmetric complex potential of arbitrary radial dependence. We consider potentials of spheroidal symmetry which are constructed from $V(r)$ by applying an angle-dependent scale transformation to the coordinate r. The scale factor is assumed to differ from unity by a small term proportional to the second zonal harmonic. The eccentricity β is defined by letting the scale change along the axis of symmetry be the factor $1+\beta$. We assume the deformed potential is free to rotate and that the incident particles satisfy the conditions of the high-energy approximation.[1] Let the amplitude for scattering through angle θ by the spherically symmetric potential $\lambda V(r)$ be $f_\lambda(\theta)$, where λ is an arbitrary parameter. Then the differential cross section for inelastic scattering at small angles may be shown to be equal to

$$\tfrac{1}{4}\beta^2\left\{\left|\left(1-\frac{d}{d\lambda}+\tan\frac{\theta}{2}\frac{d}{d\theta}\right)f_\lambda(\theta)\right|^2+3\left|\tan\frac{\theta}{2}\frac{d}{d\theta}f_\lambda(\theta)\right|^2\right\},$$

evaluated at $\lambda=1$. This result holds to all orders in the potential strength for $\beta \ll 1$.

* Supported in part by the U. S. Air Force Office of Scientific Research.
[1] R. J. Glauber, *Lectures in Theoretical Physics* (Interscience Publishers, Inc., New York, 1959), Vol. I, p. 315.

S11. On the Measurement of Photon Polarization by Pair Production. HAAKON OLSEN* AND L. C. MAXIMON, *National Bureau of Standards.*—The possibility of using pair production as a tool for measuring the linear polarization of photons has been proposed on several occasions. The calculations done thus far[1,2] seem to have displayed a paradox concerning the most probable plane of emission of the pair particles relative to the polarization plane. The reason for this discrepancy arises from the fact that the pair cross section varies rapidly when the photon and the pair particles are nearly coplanar. In an experiment, therefore, one would have to consider not exactly coplanar events but events which differ therefrom by small measurable angles. The quantitative theory pertinent to experiments has been worked out for the case of high-energy photons.

* On leave of absence from Norges Tekniske Høgskole, Trondheim, Norway.
[1] T. H. Berlin and L. Madansky, Phys. Rev. **78**, 623 (1950).
[2] G. C. Wick, Phys. Rev. **81**, 467 (1951).

S12. Scattering of Slow Neutrons by a Damped Harmonic Oscillator.* THEODORE J. KRIEGER,† *Brookhaven National Laboratory.*—The theory of the scattering of slow neutrons by harmonic oscillator is extended to include the influence of dissipative effects in the oscillator motion. The analysis is based on the damped quantum mechanical harmonic oscillator model of Senitsky,[1] who regards the dissipation as due to the coupling of the undamped oscillator to a "loss mechanism" which produces the damping. It is found that a major component of the elastic neutron peak remains unbroadened in the presence of the coupling to the loss mechanism. The inelastic peaks, however, are broadened, the broadening increasing with the number of oscillator quanta transferred. The broadening phenomenon also may be interpreted as the result of random ("Brownian") quantum jumps of the oscillator induced by the coupling to the loss mechanism.

* Work supported by the U. S. Atomic Energy Commission.
† Present address: Republic Aviation Corporation.
[1] I. R. Senitzky, Phys. Rev. **119**, 670 (1960).

S13. Electron Excitation of Collective Nuclear Transitions.* L. J. TASSIE, *Argonne National Laboratory*, AND A. S. REINER, *Weizmann Institute of Science.*—The form factors for the inelastic scattering of high-energy electrons are calculated by use of the collective model of the nucleus. For large momentum transfers the scattering depends on the form of the nuclear charge density. If it is assumed that the collective nuclear motion is irrotational and incompressible, the usual collective model can be extended to an arbitrary static charge distribution, and the inelastic scattering thus can be related to this charge distribution. Experiments are suggested which should provide a test of the assumption of nuclear incompressibility. In particular, electric monopole excitation is considered, as this should be the most sensitive to any compression effects.

* Work performed under the auspices of the U. S. Atomic Energy Commission and the U. S. Air Force (European Office).

FRIDAY AFTERNOON AT 2:00

Statler-Hilton Skytop Room

(FREDERICK SEITZ presiding)

Invited Papers in Solid-State Physics

SA1. Semi-Metals: A New Horizon. BENJAMIN LAX, *Lincoln Laboratory.* (30 min.)

SA2. Band Structure in Heavily Doped Semiconductors. P. AIGRAIN, *École Normale Supérieure.* (30 min.)

SA3. Fermi Surfaces in Solids Investigated by Ultrasonic Attenuation Method. R. W. MORSE, *Brown University.* (30 min.)

SA4. Optical Properties of Halophosphate Single Crystals. PETER D. JOHNSON, *General Electric Research Laboratories.* (30 min.)

FRIDAY EVENING AT 7:00

New Yorker, Grand Ballroom

(V. F. WEISSKOPF AND LEONARD OLSEN presiding)

Banquet of the APS and the AAPT

After-dinner speech: **Scientists and Politics.** H. A. BETHE, *Cornell University.*

SATURDAY MORNING AT 9:30

New Yorker, Boston-Washington Room

(M. L. GOLDBERGER presiding)

Theoretical Physics VI: Field Theory I

T1. Electric Dipole Approximation and the Canonical Formalism in Electrodynamics. M. SCHWARTZ, *Syracuse University.*—We consider a charged particle in an external radiation field. It will be shown that the usual identification of dynamical variables is inconsistent with the assumption that they satisfy canonical commutation rules when one also assumes that the solutions of the homogeneous equations of motion also satisfy the canonical commutation rules. We will discuss Kramer's structure independent theory in electric dipole approximation as well as an alternative structure independent formulation which yields the same equations of motion. We will show that the homogeneous solutions (which are the same in both formulations) must satisfy different commutation rules in Kramer's formulation than they do in the alternative formulation. We also will discuss the relationship of boundary conditions and the commutation rules of the homogeneous solutions to the possibility of setting up a consistent canonical formalism.

T2. Interference of Electromagnetic and Matter Waves in a Nonpermanent Gravitational Field.* C. V. HEER, *Ohio State University.*—Experimental phenomena in a nonpermanent gravitational field, i.e., the field as measured on a platform rotating with angular velocity Ω and similar to that discussed by Michelson[1] and Sagnac[2] for light, is considered for resonant cavities for electromagnetic waves and for matter waves. A resonant cavity such as a toroid that is not simply connected has the degeneracy removed by the rotation, and the resonant angular frequency of the wave traveling in the sense of rotation differs by the angular frequency of rotation Ω from the wave counter to the rotation. A "ringing" cavity yields beats at the frequency of rotation. Use of the same metric with the Klein-Gordon equation as with Maxwell's equations for the particle equivalent of the Michelson experiment yields a phase difference between paths $BCDB$ and $BDCB$ on a rotating platform of $\Delta = 8\pi A(\Omega/c)(v/c) \approx 8\pi A\Omega/\lambda_c c$. $\lambda_c = (h/m_0 c)$ is the Compton wavelength and A the area enclosed by the path $BCDB$. This is similar to the equation used by Michelson with the wavelength of light replaced by the Compton wavelength. Some feasible experiments will be discussed.

* Supported in part by the National Science Foundation.

[1] A. Michelson and H. Gale, Astrophys. J. 61, 140 (1925).

[2] G. Sagnac, J. phys. 4, 177 (1914).

T3. Strict Localization in Quantum Field Theory. JAMES M. KNIGHT,* AND J. S. TOLL, *University of Maryland.*—A definition of strict localization of states in quantum field theory is given. This definition is based on considering products of field operators, instead of particle number and position operators, as the basic measurable quantities of the theory. It is shown by an example that such states exist and have a simple physical interpretation. It can be proved that any state satisfying the definition of localization must have a nonzero probability for the presence of more than N particles, however large N may be. A simple representation of states satisfying the definition is investigated.

* Supported in part by the U. S. Air Force Office of Scientific Research and the National Science Foundation.

T4. Nonconservation of Isospin. D. FINKELSTEIN, *Yeshiva University*, J. M. JAUCH, *University of Geneva*, S. SCHIMINOVICH, *University of Buenos Aires*, AND D. SPEISER, *Institute for Advanced Study*.—In any fundamental approach to the elementary particle problem, account must be taken of the approximate nature of the law of conservation of isospin: how can such a law reflect an exact symmetry property of nature? It appears, however, that "quaternion quantum mechanics"[1] permits a symmetry that leads to a conservation law of just such an approximate nature as a result of the new noncommutativity introduced into the underlying number system of quantum mechanics. The symmetry is that of Q, the quaternions: the laws of nature do not distinguish between i, j, k. The approximately conserved quantities are the generators of this symmetry group. Violation of the conservation law occurs when Q-imaginary terms in the Hamiltonian are operative; Q-real terms lead to conservation. It has not been possible to construct Lorentz-invariant, parity-conserving, Q-imaginary Lagrangian field theories without nonlocal propagators.

[1] Birkhoff and v. Neumann, Ann. Math. **37**, 823 (1936).

T5. Numerical Solution of the Bethe-Salpeter Equation.* S. EPSTEIN AND A. MASCHKE, *University of Nebraska*.—We have studied the ladder approximation for a system of two scalar particles interacting through an intermediate scalar field. A wide range of parameters was covered, and an accuracy of about 2% was obtained using 326×326 matrices to approximate the two-dimensional integral equations which arise for each j value. For $E=0$ the results were checked against a numerical solution of Wick's[1] one-dimensional equation. A general comparison also was made with the results of a numerical solution of Gourdin's[2] approximate equation. We find that the behavior of the binding energy as a function of the mass of the intermediate boson is qualitatively the same as for the Schroedinger equation with a Yukawa potential. Our method of calculation can be used beyond the ladder approximation and also is applicable to the meson-nucleon and nucleon-nucleon problems.

* Supported in part by the U. S. Atomic Energy Commission and the University of Nebraska Research Council.
[1] G. C. Wick, Phys. Rev. **96**, 1124 (1954).
[2] M. Gourdin, Nuovo cimento **7**, 338 (1958).

T6. On a Soluble Generalization of the Thirring Model to Include Coupling with a Boson Field.* CHARLES M. SOMMERFIELD,† *Harvard University*.—A generalization of Thirring's field theory in one space dimension[1] has been investigated. The present model, which is also exactly soluble, consists of a charged, massless fermion field coupled not only to itself but also to a vector boson field with mass. The fermion Green's function is found to possess both ultraviolet and infrared divergences; however, there exists a suitable choice of the coupling constants for which the latter disappears, while the former can be removed by means of wave-function renormalization. Two charges may be defined, and there is a finite charge renormalization for each. The boson Green's function has a pole corresponding to a physical mass which differs by a finite amount from the bare mass. There is also a pole with zero mass corresponding to the generation of an electromagnetic field which, in one dimension, consists solely of gauge parts. The physical significance of these results will be discussed.

* Supported in part by the U. S. Air Force Office of Scientific Research.
† Corning Glass Works Foundation Fellow.
[1] W. Thirring, Ann. Phys. **3**, 91 (1958).

T7. Quantum Yang-Mills Field.* S. I. FICKLER AND R. L. ARNOWITT, *Syracuse University*.—The Yang-Mills field[1] has been quantized in the gauge $b_2=0$ (a similar analysis also holding in the gauges $b_1=0$ and $b_3=0$). Closed form expressions for the constraint variables have been obtained, allowing one to check the consistency of the quantization. It has been shown that the quantum "Bianchi identities" are satisfied and that the Lagrange equations are consistent with the commutation relations. The gauge transformations between any two of the gauges involves q-number gauges which are functions of the canonical field variables. Under a general q-number gauge transformation the B_μ no longer transform as in classical theory, but an additional term analogous to a heavy-particle (Yang-Lee[2]) gauge term appears. Thus the requirement of gauge invariance under q-number gauges (which indeed appear in the simple examples above) would seem to imply the existence of a heavy-particle gauge meson as well. Properties of the combined Yang-Mills, Yang-Lee system will be discussed.

* Work supported by U. S. Air Force, Aeronautical Research Laboratory, Wright Air Development Center.
[1] C. N. Yang and R. L. Mills, Phys. Rev. **96**, 191 (1954).
[2] T. D. Lee and C. N. Yang, Phys. Rev. **98**, 1501 (1955).

T8. Invariance under Improper Lorentz Transformations and the Structure of the Electromagnetic Vertex Function.* PAUL C. DECELLES, LOYAL DURAND III, AND ROBERT B. MARR, *Brookhaven National Laboratory*.—As has been noted recently by Ernst *et al.*,[1] covariance under improper Lorentz transformations is sufficient to insure in the case of spin $\frac{1}{2}$ particles that the matrix element of $\partial_\mu j_\mu$ between single-particle states vanishes independently of any assumption about the conservation of the electromagnetic current j_μ. By using the helicity representation of the single-particle states,[2] the theorem easily may be generalized to particles of arbitrary spin and to any vector current which is invariant under the combined operation of space reflection and time inversion. The helicity representation is found also to provide a very simple means of determining the number of invariant functions necessary to describe completely the single particle matrix elements of j_μ itself (i.e., the vertex), given the transformation properties of j_μ under T and P and the spins and parities of the initial and final states.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] F. J. Ernst, R. G. Sachs, and K. C. Wali, Phys. Rev. **119**, 1105 (1960).
[2] M. Jacob and G. C. Wick, Ann. Phys. **7**, 404 (1959).

T9. On the Photon Mass Renormalization. WALTER GILBERT,* *Harvard University*.—The vacuum expectation value of the time-ordered product of two conserved currents has been investigated. The limit, as points are coalesced, of a time-ordered matrix element of four Fermi operators does not converge to the current correlation function but differs from it by specific terms. In a perturbation approximation these terms may be calculated explicitly and cancel the most singular parts of the limit yielding a limit independent evaluation of this correlation function.

* Supported in part by the U. S. Air Force Office of Scientific Research.

T10. Two-Point Function and Generalized Free Fields. A. L. LICHT* AND J. S. TOLL, *University of Maryland*.†—Several theorems are proven which relate to the possibility of constructing a noninteracting field with an arbitrary two-point Wightman function. They are: (a) if $\varphi(\alpha)$ is a complete local field, and $[\varphi(\alpha),\varphi(y)]=D(\alpha-y)$, where D is an arbitrary operator depending on x and y only through their difference, then D is a c-number function; (b) such fields are generalized free fields, as defined by Greenberg[1]; (c) any generalized free field is unitarily equivalent to a superposition of Klein Gordon fields, and moreover the asymptotic condition and unitarity restrict this to a superposition of ordinary free fields with different discrete masses.

* National Science Predoctoral Fellow.
† Assisted by the U. S. Air Force through the Office of Scientific Research.
[1] O. W. Greenberg (to be published).

T11. On the Commutator of a Free Klein-Gordon Field Operator with an "Arbitrary" Heisenberg Field Operator. Z. FRIED, *U. S. Naval Ordnance Laboratory* (introduced by

H. R. REISS), AND A. L. LICHT* AND J. S. TOLL, *University of Maryland.*†—The following theorem will be proved: Let $\phi(x)$ be a free field operator satisfying the Klein Gordon equation with some arbitrary mass m. Then $[\phi(x),B(y)] = \langle 0|[\phi(x),B(y)]|0\rangle$, provided that (a) $[B(y),B(z)]_{y_0=z_0=0}$; (b) $[\phi(y),B(z)]_{y_0=z_0=0}$; (c) $[\phi(x),\Box_y B(y)]_{x_0=y_0=0}$; and (d) that $\phi(x)$, $B(y)$ together are complete, i.e., that any operator which commutes with ϕ and B is a c function.

* National Science Foundation Predoctoral Fellow.
† Assisted by U. S. Air Force Office of Scientific Research.

T12. Quantum Electrodynamics: III. The Lamb Shift. MENDEL SACHS AND SOLOMON L. SCHWEBEL, *Lockheed MSD.*—An application of the self-consistent nonsingular field theory developed earlier[1] to the case of the electron-proton system has been investigated. The approximation is made that the proton mass is infinitely large. As a result, the coupled nonlinear field equations of our theory take the linearized Dirac form for hydrogen. The Hamiltonian is the usual one plus the addition of a residual term $v=16\pi g_M(\mathbf{r}\times\boldsymbol{\alpha})_3 r^{-3}$. This operator, which gives the Lamb shift, depends on the new fundamental constant g_M with the dimensions of length (g_M is not inserted, but is automatically incorporated in the formalism[2]). Perturbation techniques are used to calculate the Lamb shift in terms of g_M. It is found that, if v is solely responsible for the Lamb effect, $g_M=(1.0436\pm0.005)\times10^{-13}$ cm. In this calculation, the zero-order Hamiltonian H_0 is taken to include a part of v. This insures that the solutions behave properly at the origin and thereby permits a perturbation expansion of operators depending on r^{-3}. The exact eigensolutions of H_0 are found to be $\psi_D\exp[-16\pi g_M(e^3/\hbar c)/r]=\psi_0\exp(-0.38\times10^{-13}/r)$, where ψ_D are the ordinary Dirac solutions. The compatibility of the value of g_M so determined with the results of the high-energy electron-proton scattering experiments will be discussed in the following paper.

[1] For Parts I and II see Bull. Am. Phys. Soc. Sec. II, 5, 505 (1960).

T13. Quantum Electrodynamics: IV. Electron-Proton Scattering and the Anomalous Magnetic Moment. SOLOMON L. SCHWEBEL AND MENDEL SACHS, *Lockheed MSD.*—The standard techniques of scattering theory have been applied to the linerarized form of the equations given in the preceding abstract. Scattering cross sections have been calculated and will be compared with those measured by the Stanford group.[1] Within the region of validity determined by the computational methods on one hand (Born approximation) and by the linearization of the coupled nonlinear equations of the self-consistent field theory[2] (mass of the proton is assumed to be infinite) on the other hand, the agreement between theory and experiment is good. The interpretation given to the scattering data by the theory will be elaborated upon. The relation of the linearized equations to the calculation of the anomalous magnetic moment of electron and/or proton will be discussed.

[1] E. E. Chambers and R. Hofstadter, Phys. Rev. 103, 1454 (1956).
[2] M. Sachs and S. L. Schwebel, "A self-consistent field theory of quantum electrodynamics," Lockheed MSD Rept., LMSD 288254 (1960).

SATURDAY MORNING AT 9:30

Statler-Hilton, Penn Top South

(E. F. SHRADER presiding)

Neutrons I

TA1. Neutrons from the He^3 Bombardment of Some Light Nuclei. I. Techniques. J. L. DUGGAN,* R. F. GABBARD,† AND P. D. MILLER, *Oak Ridge National Laboratory.*—The ion source for the Oak Ridge National Laboratory 3-Mv accelerator has been modified to provide a peak beam of about 500 μa of singly charged He^3 ions. This beam has been pulsed in the Van de Graaff terminal at a repetition rate of 2 Mcs^{-1} to give pulses of about 20-nanosec duration. After acceleration and magnetic analysis, a 2- to 3-nanosec pulse is separated from the 20-nanosec burst by a newly installed pulser operated at 12 Mcs^{-1} and synchronized with the terminal pulsing frequency. In order to detect the neutrons a large volume plastic scintillator on a 4-in. photomultiplier was used. The over-all system resolution has been about 4 nanosec for neutrons. Other elements of the time-of-flight system have been described previously.[1] The reactions $Li^7(He^3,n)B^9$ ($Q=9.346$), $Be^9(He^3,n)C^{11}$ ($Q=7.565$), and $C^{13}(He^3,n)O^{15}$ ($Q=7.126$) have been studied, and neutron time-of-flight spectra will be presented.

* ORINS Fellow from Louisiana State University.
† Summer Research Participant from University of Kentucky.
[1] W. M. Good, J. H. Neiler, and J. H. Gibbons, Phys. Rev. 109, 926 (1958).

TA2. Neutrons from the He^3 Bombardment of Some Light Nuclei. II. $Li^7(He^3,n)B^9$, $Be^9(He^3,n)C^{11}$, and $C^{13}(He^3,n)O^{15}$. P. D. MILLER, J. L. DUGGAN,* AND R. F. GABBARD,† *Oak Ridge National Laboratory.*—The excitation functions for the reactions $Be^9(He^3,n)C^{11}$ and $Li^7(He^3,n)B^9$ have been studied at 0° and 90° for He^3 bombarding energies from 1.0 to 2.5 Mev. The reaction $C^{13}(He^3,n)O^{15}$ has been studied at 0° for the same bombarding energy range. Angular distributions for the first two reactions have been measured at a bombarding energy of 2.1 Mev. The ground state and first five excited states of C^{11} were observed. All of the neutron groups were clearly resolved except those exciting the fourth and fifth excited states of C^{11} at 6.50 and 6.77 Mev. These two groups were resolved graphically. The ground state of B^9 was resolved clearly from the first excited state at 2.37 Mev, but the first and second excited states were unresolved. The three-body continuum was observed for all neutrons with energies not exceeding the ground state. At higher bombarding energies the three-body continuum becomes more prominent relative to the B^9 ground state. The spectra from the reaction $C^{13}(He^3,n)O^{15}$ show the ground state and third excited state (6.15 Mev) clearly resolved, but the first and second excited states at 5.20 and 5.25 Mev were unresolved.

* ORINS Fellow from Louisiana State University.
† Summer research participant from University of Kentucky.

TA3. Angular Yield of Neutrons from the $T(p,n)He^3$ Reaction.* M. D. GOLDBERG, J. D. ANDERSON, J. P. STOERING, AND CALVIN WONG, *Lawrence Radiation Laboratory, Livermore.*—Angular-yield curves of neutrons from the $T(p,n)He^3$ reaction have been obtained for incident laboratory proton energies of 3.4, 4.3, 5.0, 6.5, 8.0, 8.8, 10.3, 11.5, and 12.4 Mev. The neutrons were detected by a plastic scintillator, and standard time-of-flight techniques were used to separate the monoenergetic neutron group from background neutrons and gamma rays. The yield curves in the center-of-mass system indicate

substantial backward peaking. This can be explained qualitatively with a direct interaction model in which deuteron-core pickup by the proton is more prominent than nucleon exchange.[1] Above about 8-Mev proton energy, a broad maximum appears at about 80° (c. m.) and persists through the highest energy measured. When the data are normalized to unpublished absolute $\sigma(0°)$ telescope measurements[2] below 5.5 Mev, the total integrated cross sections at 3.4, 4.3, and 5.0 Mev are in excellent agreement with unpublished integrated cross sections obtained with a well-calibrated long counter by the Los Alamos group.[2]

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] James E. Young and Paul R. Stein, Los Alamos Scientific Laboratory (to be published).
[2] John D. Seagrave, paper presented at the Conference on Nuclear Forces and the Few-Nucleon Problem, London, 1959 (Pergamon Press, to be published).

TA4. (n,p) Reactions in Intermediate Nuclei.* F. L. HASSLER, *Brown University*.—The angular distributions of protons emitted from targets of Mg, Al, Si, P, S, Tl, Fe, Co, Ni, and Zn during bombardment by 14-Mev neutrons were studied at 30° intervals from 0° to 150°. The results were analyzed to give nuclear temperatures and cross sections. In addition, the front-back asymmetry was used to separate direct interaction contributions from compound nucleus yields, and in some cases the shape of the compound nucleus portion of the yield was used to predict σ, governing[1] the angular momentum distribution of levels in the final nucleus. The measured cross sections are generally in agreement with previous values. The experimental temperatures agree well with predictions from theoretical considerations of shell-dependent Fermi gas models and with a parameter[1] τ, reflecting the low excitation level scheme of the residual nuclei. The σ values obtained are consistent with values estimated independently.[1] The separation of direct interaction and compound nucleus predictions are compared with a semiempirical calculation.[2]

* Supported in part by U. S. Atomic Energy Commission.
[1] T. Ericson, Nuclear Phys. 11, 481 (1959).
[2] G. Brown and H. Muirhead, Phil. Mag. 2, 473 (1957).

TA5. Fast-Neutron Detection Using Directional and Pulse Shape Discrimination.* D. W. KENT AND W. P. BUCHER, *Bartol Research Foundation*.—Left-right asymmetry measurements using partially polarized neutrons from the $D(d,n)He^3$ reaction must be carried out in the presence of a background flux containing energetic room-scattered neutrons as well as γ rays produced from the room and from inelastic scattering sample collisions. A cylindrical mold containing liquid scintillant and glass has been constructed so that elastically scattered neutrons are accepted only in the scatterer-detector plane. The undesirable neutron component of the background is thereby reduced to an extent which considerably increases the statistics of left-right measurements. A stack of fifty Pyrex sheets 0.005 in. thick, each separated by three supports of 0.0035-in.-diam glass thread, is immersed in a toluene based scintillant solution, forming a total sensitive volume of approximately 1.7 cc. Elimination of γ rays is achieved by pulse shape discrimination in a circuit which gates the multi-channel pulse height analysis of detector events.

* Assisted by the U. S. Atomic Energy Commission.

TA6. Fast-Neutron Total Cross Sections of B^{10} and B^{11}. R. L. WALTER, D. B. FOSSAN, AND C. H. POPPE, *University of Wisconsin*.*—The total neutron cross sections of B^{10} and B^{11} were measured from 3.4- to 15.4-Mev neutron energy. Below 9.5-Mev, neutrons were produced by bombarding an about 30-kev thick tritium gas target with protons. Neutrons above 9.5 Mev were produced with the $D(d,n)$ reaction using a deuterium gas target about 40 kev thick. Several of the narrow peaks which were observed in the B^{11} cross section were further investigated by using a 15-kev thick zirconium-tritium target. Fourteen peaks varying in width from 20 to 180 kev appeared in the B^{11} cross section below 9.8 Mev (12.4-Mev excitation energy). Above this energy the cross section was flat to within 0.1 barn. The B^{10} cross section exhibited no structure except for a broad maximum at 5.1 Mev approximately 700 kev wide and 0.25 barn high. Previous measurements on B^{10} at lower energies likewise have shown only broad peaks, the narrowest being 300 kev wide at 1.75 Mev (13-Mev excitation energy). The behavior of the B^{10} and the B^{11} cross section is similar to that observed earlier[1] for Be, C, and O in that no sharp peaks occur for neutron energies greater than about 12-Mev excitation energy.

* Work supported by the U. S. Atomic Energy Commission and by the Wisconsin Alumni Research Foundation.
[1] D. B. Fossan, T. H. May, R. L. Walter, and W. E. Wilson, Bull. Am. Phys. Soc. Ser. II, 5, 369 (1960).

TA7. Inelastic Neutron Scattering from F^{19} and Ta^{181}. W. L. ROGERS, D. I. GARBER, AND E. F. SHRADER, *Case Institute of Technology*.—The differential inelastic neutron scattering cross sectons of F^{19} and Ta^{181} have been measured using the neutron time-of-flight technique. For F^{19} primary neutron energies of 565 kev and 1000 kev were used, and the inelastic scattering leaving the fluorine nucleus excited to its 109-kev and 197-kev levels was observed. For Ta^{181}, primary neutron energies of 710 kev and 900 kev were used and the inelastic neutron scattering leaving the tantalum nucleus excited to its 133-kev and 303-kev levels was observed. For both nuclides the inelastic scattering is essentially isotropic. The scattering cross sections in barns are as follows: F^{19}, $\sigma(109\text{ kev})=0.54\neq0.17$, $\sigma(197\text{ kev})=1.35\neq0.25$ at $E_n=565$ kev; Ta^{181}, $\sigma(137\text{ kev})=1.2\neq0.1$, $\sigma(303\text{ kev})=0.2\pm0.1$ at $E_n=710$ kev; and $\sigma(137\text{ kev})=1.1\pm0.1$, $\sigma(303\text{ kev})=0.5\pm0.1$ at $E_n=900$ kev. In addition, for Ta^{181} the differential cross section at 90° has been measured at a function of incident neutron energy up to 1.00 Mev. The elastic scattering from C^{12} was used as a secondary standard for determining the absolute cross sections. The observed angular distribution of elastic scattering from C^{12}, F^{19}, and Ta^{181} agree well with published literature.

TA8. Gamma Rays from Inelastic Scattering of 14-Mev Neutrons from Carbon, Nitrogen, and Oxygen.* J. B. ASHE, J. H. MCCRARY, I. L. MORGAN, AND J. T. PRUD'HOMME, *Texas Nuclear Corporation*.—An anticoincidence annulus gamma-ray spectrometer of the type described by Trail and Raboy[1] has been used to study the gamma rays emitted from C, N, and O when samples of these materials are bombarded with 14-Mev neutrons. A technique has been developed for gating the multichannel pulse-height analyzer on with pulses from the annulus corresponding to the absorption of 0.511-Mev radiation in the annulus. This "one escape gating" places more stringent requirements on the pulses being analyzed and thus reduces appreciably the background counting rate over that obtained from using the annulus merely as a anticoincidence shield.

* Supported in part by the U. S. Army Engineer Research and Development Laboratories, Fort Belvoir, Virginia.
[1] C. C. Trail and Sol Raboy, Rev. Sci. Instr. 30, 425 (1959).

TA9. Angular Distribution of 2.6-Mev Gamma Rays from the Reaction $Pb^{208}(n,n'\gamma)Pb^{208}$.* D. J. DONAHUE, *Pennsylvania State University*.—Gamma rays produced through inelastic scattering by lead of a well-collimated beam of fast neutrons from a reactor have been detected with a NaI(Tl) crystal. By using targets of natural lead and lead enriched in the isotope Pb^{208}, the most intense γ rays present have been identified as the 0.80-Mev γ ray from Pb^{206} and the 2.6-Mev γ ray from Pb^{208}. The product of the shape of the fission spectrum and the statistical theory shape of the cross section for production of 2.6-Mev γ rays from Pb^{208} indicates that about 70% of the neutrons producing these γ rays have energies between 3.5 and 6.0 Mev. The relative yield of the 2.6-Mev

γ rays as a function of the angle between the neutron beam and the direction of γ ray emission has been studied for angles between 100° and 150°. The angular distribution so obtained is compared with the distribution predicted by the theory of Satchler.[1]

* Supported in part by the U. S. Atomic Energy Commission.
[1] G. R. Satchler, Phys. Rev. **104**, 1198 (1956).

TA10. Neutron Capture Gamma Rays from Lead.* E. T. JURNEY, R. E. CARTER, AND H. T. MOTZ, *Los Alamos Scientific Laboratory.*—Gamma rays of 7370 and 6740 kev due to $Pb^{207}(n,\gamma)Pb^{208}$ and $Pb^{206}(n,\gamma)Pb^{207}$ are found to have an intensity ratio of 10±1 for natural lead, in agreement with previous work.[1,2] If no other gamma-ray transitions occur for these reactions, then the observed intensity ratio should correspond to the absorption cross sections. Ten weak gamma rays are observed between 2.5 and 6.7 Mev, but their total intensity cannot alter the Pb^{207}/Pb^{208} capture ratio to be greater than 13. Pile oscillator absorption cross section measurements give a capture ratio of 27±5 for natural lead.[3] Only one of the observed weak lines (2617 kev) shows any simple correlation with known excited states in lead. The remaining nine weak lines might be due to impurities. A theoretical estimate of a transition to the first excited state of Pb^{207} is 0.3 for direct capture.[4] No such line of 5.8 Mev is seen with an intensity limit of 0.04 of the 6740-kev ground-state transition of $Pb^{206}(n,\gamma)Pb^{207}$.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] B. B. Kinsey, G. A. Bartholomew, and W. H. Walker, Phys. Rev. **82**, 380 (1951).
[2] B. P. Ad'yasevich, L. V. Groshev, and A. M. Demidov, Conference, Academy of Sciences U.S.S.R., on *Peaceful Uses of Atomic Energy* (Consultants Bureau, New York, 1955), p. 195.
[3] Aitken *et al.*, Proc. Phys. Soc. (London) **A65**, 761 (1952).
[4] A. M. Lane and J. E. Lynn, Nuclear Phys. **17**, 586 (1960).

TA11. Delayed Neutrons from the Noble Gases.* A. F. STEHNEY AND G. J. PERLOW, *Argonne National Laboratory.*—Two new delayed-neutron precursors were found when gas-flow techniques similar to those described in our work on halogens[1] were applied to Kr and Xe fission products. A solution of uranium was irradiated with slow neutrons in the Argonne research reactor, CP-5, and the gases were then swept into an evacuated glass container where BF_3 counters were used to count fast neutrons. Adequate precautions were taken to prevent contamination from the halogen delayed-neutron precursors.[1] Spurious effects due to photoneutron production were found to be negligible. Counting rates of about 2000 per sec were typical for neutrons at the start of counting, 2 sec after irradiations of 12-sec duration. The neutron-decay data showed the presence of a Kr delayed-neutron precursor of about 1.5-sec half-life and a Rb precursor of about 6-sec half-life in sevenfold smaller neutron yield; little, if any, neutron activity was found in the Xe fraction. The Rb precursor grew in from a Kr parent having a half life of about 2 sec. One of the new precursors may be assigned to Kr^{93-94} and the other to Rb^{99} or Rb^{93} on the basis of reported half-lives. The combined neutron yield for the two precursors is about 0.5% of the total delayed-neutron yield from U^{238}.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] G. J. Perlow and A. F. Stehney, Phys. Rev. **113**, 1269 (1959).

TA12. Delayed Neutron Groups from N^{17}.* G. J. PERLOW, A. F. STEHNEY, W. J. RAMLER, AND J. L. YNTEMA, *Argonne National Laboratory.*—The energy of the neutrons which follow the β decay of 4.1-sec N^{17} was measured by means of a neutron spectrometer[1] in which the energies of proton recoils were determined in a triple proportional-counter arrangement. The energy calibrations were made with monoenergetic neutrons from $Li^7(p,n)Be^7$ at the Van de Graaff generator. The N^{17} was produced in the reaction $C^{14}(\alpha,p)N^{17}$ at a mean energy of about 25 Mev. The C^{14} was in the form of a 14-mg pellet of 41% enrichment sandwiched in aluminum foil. Bombardment and counting were alternated by shuttering the cyclotron beam. Two groups of neutrons were observed with energies of 1.225±0.060 and 0.425±0.020 Mev and relative intensities in the ratio 1.6:1. Within a small energy discrepancy, these correspond to β transitions to the $\frac{3}{2}^-$ states of O^{17} at 5.38 Mev and 4.56 Mev. The higher energy neutrons reported by Hayward[2] would not have been observed.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] G. J. Perlow, Rev. Sci. Instr. **27**, 460 (1956).
[2] E. Hayward, Phys. Rev. **75**, 917 (1949).

SATURDAY MORNING AT 9:30

New Yorker, Grand Ballroom

(GREGORY BREIT presiding)

Nucleonic Scattering; Fundamental Particles

U1. Detailed Analysis of p-p Scattering Data.* PETER SIGNELL, *The Pennsylvania State University.*—The p-p scattering data at 95 Mev are shown to "demand" the one-pion-exchange force, while the data at 310 Mev do not. The detailed differences at the two energies are brought out by comparison to what one would expect if the data were infinitely precise. Some apparent errors in the data are located.

* Supported in part by the U. S. Atomic Energy Commission.

U2. Measurement of the Triple Scattering Parameter D at 210 Mev.* KAZUO GOTOW, ERNST HERR, AND FREDERICK LOBKOWICZ, *University of Rochester.*—As part of a program to determine the p-p scattering matrix completely at 210 Mev, we have measured the depolarization parameter D in a triple scattering experiment. The polarized proton beam of the Rochester 130-in. synchrocyclotron was scattered in a plane vertical to the polarization vector from liquid hydrogen. The degree of polarization of the scattered beam in the direction vertical to the scattering plane was then measured, using the polarimeter described previously.[1] From these measurements performed for left and right second scattering and from the calibration measurements in the direct proton beam, polarization and depolarization D in p-p scattering have been obtained for θ_{cm} 30°, 40°, 50°, 60°, 70°, 80°, and 90°.

* Supported in part by the U. S. Atomic Energy Commission.
[1] E. Heer, J. Tinlot, W. Gibson, and A. England, Bull. Am. Phys. Soc. Ser. II, **4**, 252 (1959).

U3. Slightly Inelastic Proton-Deuteron Scattering at 160 Mev.* DOUGLAS STAIRS† AND RICHARD WILSON, *Harvard University.*—The slightly inelastic scattering of 160-Mev protons by deuterons is of interest since it provides information, otherwise difficult to obtain, about the $T=0$ state. In

this region the incident proton dissociates the deuteron, leaving a small relative momentum in the resultant n-p system. Since the momentum transfer is the same order of magnitude as the internal momentum of the deuteron, interference between the n-p and p-p scattering amplitudes is important. Protons scattered from a ½-in. deuterium target were analyzed by a magnetic spectrometer. With an over-all energy resolution of 1%, this apparatus clearly separates the inelastic continuum from the much larger elastic peak. By filling the same target with hydrogen, a calibration of the apparatus is obtained, as well as the shape of the elastic peak. The energy spectra of scattered protons have been measured at four angles. The results are discussed and compared with the calculations of Cromer.[1]

* Supported by the Office of Naval Research.
† Supported by the National Research Council of Canada.
[1] Alan H. Cromer, abstract S9 in this bulletin.

U4. Preliminary Results on the Helicity of the Proton.* J. LEITNER, E. HARTH, Y. RHEE, AND J. WESTGARD, *Syracuse University*, M. BLOCK, B. BRUCKER, C. CHANG, R. GESSAROLI, T. KIKUCHI, A. KOVACS, AND C. MELTZER, *Duke University*, H. COHN, *Oak Ridge National Laboratory*, A. PEVSNER, P. SCHLEIN, AND R. STRAND, *Johns Hopkins University*, AND L. LENDINARA, L. MONARI, AND G. PUPPI, *University of Bologna*.—Parity nonconservation in a Λ decay induces a longitudinal polarization of the proton in the Λ rest frame. In the laboratory frame this appears as a transverse polarization proportional to α, the Λ decay asymmetry parameter. If the decay proton undergoes a subsequent elastic nuclear scattering, the transverse polarization can be detected by measuring the right-left asymmetry in an azimuthal scatter angular distribution. Previous experiments which measured this asymmetry in p-iron and p-carbon scattering have yielded contradictory results. Both experiments, however, are subject to a possible contamination by inelastic scattering. From an exposure of the helium bubble chamber to a low-energy K beam at the Bevatron, we have obtained a sample of about 20-Δ decay protons which undergo subsequent scattering from helium. Since there are no excited states of helium, and since the scattered proton energy is low enough to be measured accurately by means of range, it is possible to rule out all inelastic contamination. The observed sample has an average transverse polarization of $-0.80\ \alpha$. Within the acceptance criteria, the observed average analyzing polarization is ~35%. The sample is now being analyzed to obtain the sign of α (the negative of the proton helicity).

* This research is supported in part by the Office of Naval Research, the U. S. Atomic Energy Commission, Office of Scientific Research, and the National Science Foundation.

U5. Experimental Limits for the Electron-Proton Charge Difference and for the Neutron Charge.* JENS C. ZORN, GEORGE E. CHAMBERLAIN, AND VERNON W. HUGHES, *Yale University*.—Although a small limit for the electron-proton charge difference has been established, the possibility of a finite difference continues to be of interest. Feinberg and Goldhaber have pointed out that any electron-proton charge difference would allow the conservation of baryons to be deduced from the conservation of charge; Lyttleton and Bondi have shown that an electron-proton charge difference of 2 parts in 10^{18} may form the basis for a theory of the expanding universe. We have established upper limits to the charges of Cs and K atoms by observing the deflection of an atomic beam in a homogeneous electric field. The results are: $q(\mathrm{Cs}) = (1.0 \pm 5.1) \times 10^{-17} |q_e|$ and $q(K) = (4.1 \pm 9.3) \times 10^{-17} |q_e|$, where q_e is the value of the electron charge; uncertainties correspond to the standard error. If we assume total atomic charge is $Z\delta q + Nq_n$, where Z is the number of protons, $\delta q = q_p + q_e$, q_p the proton charge, N the number of neutrons, and q_n the neutron charge, then $\delta q = (-0.9 \pm 2.2) \times 10^{-17} |q_e|$ and, independently, $q_n = (0.6 \pm 1.6) \times 10^{-17} |q_e|$. If $\delta q = q_n$ as required for charge conservation in beta decay, then $\delta q = (0.8 \pm 3.8) \times 10^{-19} |q_e|$ which is substantially less than the value required by the theory of Lyttleton and Bondi.

* This research has been supported in part by the National Aeronautics and Space Administration.

U6. Experimental Limit on the "Charge" of the Photon.* L. GRODZINS, D. ENGELBERG, AND W. BERTOZZI, *M.I.T.*—The effect of an electric field on the energy of 14.4 kev photons emitted from Fe^{57} is being investigated with the use of recoilless resonance scattering. The source, ~1 mC Co^{57} plated onto iron, is stationary, and the 0.6-mil natural iron absorber moves back and forth at a speed of 0.0107 cm/sec, the maximum slope point of the resonance absorption line. The counting rates for forward and backward motions are stored in separate scalers. An electric potential of +20 000 v on the source is periodically switched off; the counting rate with and without potential are stored in separate registers. Neither an energy shift nor a line broadening has been observed due to the electric field. If a charge q_{ph} is attributed to the photon which would lead to an energy shift $q_{ph}V$ as the photon crosses the potential V, then our present experimental limit on such a charge is $q_{\mathrm{photon}} \leq 1 \times 10^{-18} q_{\mathrm{electron}}$.

* This work is supported in part by funds provided by the U. S. Atomic Energy Commission, the Office of Naval Research, and the Air Force Office of Scientific Research.

U7. Electromagnetic Properties of the Proton Core.* D. N. OLSON, H. F. SCHOPPER, AND R. R. WILSON, *Cornell University*.—Measurements of electron-proton scattering made at Cornell[1] and Stanford[2] below 1000 Mev have shown that F_1 and F_2, the electric and magnetic form factors, are not equal; indeed that F_2 is nearly zero for values of q, the momentum-energy transfer, of about $5f^{-1}$, while F_1 approaches a constant value of roughly ½. Preliminary new results at higher values of q indicate a decrease in F_1. Thus, for electrons of 1200 Mev scattered at 112°, corresponding to a q of $6f^{-1}$, our measured cross section is $(2 \pm 1) \cdot 10^{-34}$ cm²/sr. Such a small cross section can arise because both F_1 and F_2 are small, i.e., about 0.2 or 0.3, indicating that the core of the proton has a radius of perhaps 0.4 fermis and a charge of ½e. Alternatively, the magnetic moment of the core might be reversed, in which case F_2 would be negative giving some destructive interference with F_1; the values of F_1 and F_2 might then be as large as 0.4 and -0.2. We presently are trying to distinguish between these possibilities which appear to correspond to interesting properties of the proton core.

* Supported by joint contract of Office of Naval Research and the U. S. Atomic Energy Commission.
[1] R. Wilson, K. Berkelman, J. Cassels, and D. Olson, Nature **188**, 94 (1960).
[2] F. Bumiller, M. Croissiaux, and R. Hofstadter, Phys. Rev. Letters **5**, 261 (1960).

U8. Proton-Proton Collisions at 1.35, 2.1, and 2.9 Bev. G. B. CHADWICK, G. B. COLLINS, AND T. FUJII, *Brookhaven National Laboratory*, N. C. HIEN, *Carnegie Institute of Technology*, AND P. J. DUKE, *National Institute for Research in Nuclear Science, Harwell*.—Following the work of Chadwick *et al.*[1] the momentum distribution of secondary protons produced in proton-proton collisions has been measured at energies of 1.35, 2.1, and 2.9 Bev and at several angles. The incident protons from the Cosmotron traversed a liquid hydrogen target, and after momentum analysis the secondary particles were detected by a scintillation counter hodoscope and a gas Čerenkov counter. The latter was used in anticoincidence to separate protons and pions. The total momentum resolution (obtained from the width of the elastic peak) was 2.3%. The pronounced maximum in the momentum spectrum produced by the 1.23-Bev mass isobar which corresponds to the $(\frac{3}{2},\frac{3}{2})$ resonance in the

π^+-proton system was clearly separated from the peak produced by the elastic proton scattering at all three energies and at angles of 2.75°, 3.5°, and 4.7° in the laboratory system. There was also evidence at 2.1 and 2.9 Bev for the formation of isobars corresponding to the $T=\frac{1}{2}$ resonances of the π^-–proton system. Detailed results will be presented.

[1] G. B. Chadwick, G. B. Collins, C. E. Swartz, A. Roberts, S. DeBenedetti, N. C. Hien, and P. J. Duke, Phys. Rev. Letters **4**, 611 (1960).

Invited Papers

U9. Phase-Parameter Analysis of (n,p) Scattering. M. H. HULL, JR., *Yale University.* (30 min.)
U10. Precise (n,p) Cross-Section Measurements below 10 Mev. C. E. ENGELKE, *Columbia University.* (30 min.)

SATURDAY MORNING AT 9:30

Statler-Hilton Skytop Room

(H. A. BOORSE presiding)

Invited Paper

UA1. Ions in Liquid Helium: A Microscopic Method for Studying Superfluidity. FREDERICK REIF, *University of California, Berkeley.*

Cryogenics

UA2. Critical Velocities in Liquid Helium. R. MESERVEY, *Yale University.*—The stability of steady-state low-velocity laminar flow of the normal component of liquid helium can be justified by the principle that, in such quasi-equilibrium conditions, the rate of entropy production is a minimum consistent with the external constraints. Two fluid equations which contain a nonlinear mutual friction term imply a condition for which the justification of stable laminar flow is no longer valid and a change of flow regime is expected. This instability condition predicts the magnitude and temperature dependence of most critical velocities which have been observed in channels wider than 10^{-3} cm.

UA3. Growth of Mutual Friction in a Heat Current in Liquid Helium II.* S. M. BHAGAT, *Carnegie Institute of Technology,* AND P. R. CRITCHLOW, *University of British Columbia* (introduced by S. A. Friedberg).—The growth of mutual friction has been studied in an 800-μ capillary of length 150 cm. The temperature difference due to the normal viscosity is observed as a rapid rise. When the heating current is larger than a certain critical value, this is followed by a slow growth having one or more linear parts. These are interpreted as the spreading of a uniform density of turbulence along the capillary at a constant speed. This speed of propagation is partially governed by the direction of spread with respect to the superfluid flow. It is suggested that vorticity is generated at a constant rate in a localized region and that, when the density of turbulence reaches a certain value, determined by the heating current, it cannot increase further and therefore spreads along the capillary at a constant speed.

* Work performed at The Clarendon Laboratory, Oxford, England.

UA4. Thickness of the Moving He II Film. P. W. F. GRIBBON AND L. C. JACKSON, *Royal Military College of Canada.*—The polarized light method for the measurement of the thickness of the He II film has been used to obtain an extensive series of measurements on the moving film over the average of heights from 0.3 cm to 1.2 cm at 1.68°K. A stainless steel beaker, on the outside of which is a longitudinal plane mirror, was filled with He II, and the thickness of the moving film on the outside of the beaker was measured as the beaker emptied by film transfer. The moving film was less than 5% thinner than the stationary film. The measured decrease in thickness is 17% of the theoretical value at 1.68°K and of the order of 30% at 1.83°K.

UA5. Adsorption of Helium on Saran Charcoal at Temperatures below 5°K. M. H. EDWARDS AND J. R. DACEY, *Royal Military College.*—Adsorption isotherms and isosteres of He^4 on Saran charcoal have been measured between 5°K and 0.9°K using a McBain-Baker quartz spiral microbalance and a booster cryostat. The charcoal became saturated at very low pressures; so low that thermal contact between the bath and the suspended specimen could not be established for partial monolayers or for the lowest temperatures. Thus heats of adsorption could be obtained only for fairly high coverages when the actual pressure was more than 10^{-4} mm Hg. The average pore diameter for this type of charcoal is about 12 A. From the measured pore volume and the total mass adsorbed, we infer that the adsorbed helium is greatly compressed.

UA6. Ten-Kilogauss Superconducting Solenoid; Resistive Transition in Superconducting Niobium. S. H. AUTLER, *Lincoln Laboratory,** AND L. J. DONADIEU, *R.L.E., M.I.T.*—The maximum field strength obtained with a superconducting niobium solenoid[1] has been extended to 9.8 kgauss at 1.5°K and 7.1 kgauss at 4.2°K. The solenoid consists of a Teflon form holding two windings in parallel of 0.004-in.-diam unannealed niobium wire. The resistance transitions of short samples of niobium wire in various states of strain were studied as a function of the current in the wire, applied transverse magnetic field strength, and temperature. The field strength H and current I at which a barely observable voltage appeared across the samples obey relationships of the form $H=H_0-A\log I$ over more than 5 decades of current. No evidence of a true resistance discontinuity was seen. Implications for the design of superconducting solenoids and the possibility of generating fields somewhat higher than 10 kgauss with niobium will be discussed.

* Operated with support from the U. S. Army, Navy, and Air Force.
[1] S. H. Autler, Rev. Sci. Instr. **31**, 369 (1960); S. H. Autler, Bull. Am. Phys. Soc. Sec. II, **5**, 366 (1960).

UA7. Superconductive Properties of Thin Tin Films.* JOHN N. COOPER AND E. C. CRITTENDEN, JR., *U. S. Naval*

Postgraduate School and Space Technology Laboratories, AND F. W. SCHMIDLIN, *Space Technology Laboratories*.—The superconductive properties of a carefully prepared family of eight thin tin films with thicknesses varying from 0.03μ to 1.04μ have been studied in the temperature range between 1.5 and 3.9°K. The films were prepared by vacuum evaporation upon polished glass substrates cooled to −20°C. Film thicknesses were measured by Fabry-Perot interferometry and also were calculated both from mass evaporated and from resistance measurements. Critical temperatures, particularly for the thinner films, were substantially above that for bulk tin, presumably because of tensile stresses. The dc critical currents as a function of thickness t can be well approximated by an expression of the form $A(1-e^{-t/\sigma})/(1+e^{-t/\sigma})$, where A is a constant determined by the temperature and σ is about 0.16μ, essentially independent of temperature.

* Supported in part by the Office of Naval Research.

UA8. Dependence of the Surface Magneto-Resistance and Magneto-Reactance of Superconducting Tin on Sample Purity at 3 kMc/sec. P. L. RICHARDS,* *Royal Society Mond Laboratory*.—The anomalous decrease in the surface resistance R and reactance X of superconducting tin when less than critical magnetic fields are applied[1] has been investigated as a function of sample purity. This negative surface magneto-impedance is especially interesting since the application of a field nearly equal to the critical field appears to drive the superconductor away from the normal state. In single crystal rods oriented along the (110) direction, the negative changes in R and X with field, which are quite pronounced above about 0.9 of the critical temperature in pure tin,[1] disappear when a few hundredths to a few tenths percent of indium are added. This is the purity range in which the extreme anomalous limit of the skin effect begins to fail. The Dresselhaus theory predicts that, as the classical limit of the skin effect becomes valid, R will increase with field and X will decrease. This is in clear disagreement with our observation that both R and X increase with field as more indium is added.

* National Science Foundation Postdoctoral Fellow, now at Bell Telephone Laboratories, Inc., Murray Hill, New Jersey.
[1] P. L. Richards, *Proceedings of the VIIth International Conference on Low Temperature Physics* (University of Toronto Press, Toronto) (to be published).

UA9. Critical Fluctuations in Superconductors.* K. GOTTFRIED, *Harvard University*, AND L. P. KADANOFF, *University of Copenhagen*.—The existence of critical fluctuations follows directly from the Cooper effect. In terms of time-dependent correlation functions, the Cooper pairing manifests itself as an instability of $R(\mathbf{r},t)=\langle\psi_\uparrow(\mathbf{r}t)\psi_\downarrow(\mathbf{r}t)\psi_\downarrow^\dagger(0)\psi_\uparrow^\dagger(0)\rangle_T$ as $T\to T_c$; in fact the form of $R(\mathbf{r},0)$ is exactly that of the Ornstein-Zernike correlation function. This leads us to ask whether any phenomena analogous to critical opalescence occur in the vicinity of T_c. Since $\psi_\uparrow(\mathbf{r}t)\psi_\downarrow(\mathbf{r}t)$ cannot be coupled to an external field, R itself is not measurable. R actually describes the effective interaction between electrons; thus its anomalous behavior at T_c results in a resonant electron-electron scattering amplitude near the Fermi surface. The linear response, on the other hand, is described by functions of the type $D(\mathbf{r},t)=\langle\psi_\sigma^\dagger(\mathbf{r}t)\psi_{\sigma'}(\mathbf{r}t)\psi_{\sigma'}^\dagger(0)\psi_\sigma(0)\rangle_T$. Therefore our question reduces to determining the influence of the aforementioned resonance on entities like D. For this purpose we have constructed Boltzmann-like integral equations which connect D and R. The somewhat inconclusive results we have found will be discussed.

* Supported in part by the U. S. Air Force Office of Scientific Research.

UA10. Transverse Collective Oscillations in Superconductors.* RICHARD A. FERRELL, *University of Maryland*.—Transverse collective waves in superconductors can be treated similarly to plasmons in a degenerate electron gas.[1] A discrete exciton can separate from the continuum and be pulled down into the energy gap without phonon exchange or Coulomb interaction but as a result of only the magnetic interaction of the quasi-particle and hole. This type of exciton is not an eigenstate of the BCS Hamiltonian and occurs only when the magnetic interaction terms are added to the Hamiltonian. The criterion for the exciton to separate from the continuum is identical to that for free propagation of light at a frequency below the gap frequency. It requires that the positive polarizability due to absorptions above the gap be strong enough to cancel the negative London polarizability. Although more complicated, such an electromagnetic window in the gap is analogous to the well-known optical window of silver films in the near ultraviolet. A further nonnegligible electromagnetic collective effect in superconductors is the excitation of ordinary transverse phonons.

* Investigation supported by the Office of Naval Research.
[1] R. A. Ferrell and J. J. Quinn, Phys. Rev. **108**, 570 (1957).

UA11. Direct Measurement of the Superconducting Energy Gap. JAMES NICOL, SIDNEY SHAPIRO, AND PAUL H. SMITH, *Arthur D. Little, Inc.*—The phenomenon of electron tunneling through a thin insulating layer between two metals, both of which are maintained in the superconducting state, provides a direct measure of the superconducting energy gap. The tunneling current vs voltage characteristic of an experimental sandwich of Al-Al_2O_3-Pb exhibits negative resistance regions symmetric about the origin. Analysis shows the way in which the negative resistance regions measure the superconducting energy gap directly. Measured values for the full limiting gaps for lead and aluminum are, respectively, $(4.35\pm0.10)kT_c$ and $(2.7\pm0.3)kT_c$ with the transition temperatures taken as 7.2°K for lead and 1.2°K for aluminum. Experimental curves are compared with calculations based on the superconducting density-of-states function given by Bardeen, Cooper, and Schrieffer.

SATURDAY MORNING AT 9:30

New Yorker, Terrace Room

(S. A. KORFF presiding)

Invited Papers

V1. Interaction of Cosmic-Ray Modulating Fields in Interplanetary Space. JUAN ROEDERER, *Comision Nacional de Energia Atomica, Buenos Aires*. (30 min.)

V2. Leakage Neutrons and the Van Allen Radiation Belt. W. N. HESS, *Lawrence Radiation Laboratory, Livermore*. (30 min.)

V3. Nuclear Measurements Related to Astrophysical Processes. W. A. S. LAMB, *Lawrence Radiation Laboratory, Livermore*. (30 min.)

V4. Measurement of $g-2$ for the Mu Meson. R. L. GARWIN, *CERN*. (30 min.)

SATURDAY MORNING AT 9:30

New Yorker, Panel Room

(H. PRIMAKOFF presiding)

Theoretical Physics VII: Nuclear Reactions

VA1. Trends in (n,p) Cross Sections around 14 Mev. DONALD G. GARDNER, *University of Arkansas.*—An empirical equation has been found which predicts very well the (n,p) cross sections around 14 Mev for all isotopes of elements from potassium to zinc and with somewhat less success for elements down to carbon. The equation is a function of *atomic number only.*

$$\sigma(Z,A)=0.0222\,A\exp[0.0867\,A-0.035(Z-22)].$$

This equation predicts the cross section for the isotope with mass number $A=2Z+4$ for each value of Z used. To find the cross sections for the other isotopes of an element one uses the equation $\sigma_Z(A\pm n)=\sigma_Z(A)2^{\mp n}$. Thus the cross section for each successive isotope decreases by a factor of 2. This decrease is in accordance with the Levkovskii trends. In the range $Z=19$ to $Z=30$ only nickel deviates appreciably from the predicted values. This is to be expected since nickel has a closed proton shell ($Z=28$). It is interesting that such factors as reaction Q value, density of excited states, value of the total nonelastic neutron cross section, neutron closed shells, and odd or even numbers of nucleons do not have to be included in the above equation.

VA2. Coupled Square Well Model for Elastic Scattering. D. E. BILHORN,* *Rice University,* AND W. TOBOCMAN,*† *Case Institute of Technology.*—A simple model for s-wave neutron scattering is provided by representing the scattering potential by a pair of coupled square wells. Such a model produces resonances that exhibit the giant resonance effect.[1] We have compared isolated resonances given by this model with the Breit-Wigner formula for two types of coupling. We find that for a resonance with a width of about 16 kev the resonant part of the scattering does indeed have the Breit-Wigner form. The resonance energy is found to be considerably shifted from the energy of the bound state that exists in the zero coupling strength limit. Also the nonresonant part of the scattering amplitude is considerably different from both the hard sphere scattering amplitude and the zero coupling strength limit scattering amplitude. This last result is in accord with expectations.[2]

* Supported in part by the National Science Foundation.
† On leave of absence from Rice University.
[1] W. Tobocman and D. E. Bilhorn, Phys. Rev. 115, 1275 (1959).
[2] A. M. Lane and R. G. Thomas, Revs. Modern Phys. 30, 273 (1958).

VA3. Gamma-Rays Following Direct Inelastic Scattering from Nuclei. G. R. SATCHLER, R. M. DRISKO, AND R. H. BASSEL, *Oak Ridge National Laboratory.*—The distorted wave Born approximation theory of direct reactions has been used to interpret the experimentally observed angular correlation of γ rays following the inelastic scattering of protons and alpha particles at medium energies. The distorted waves were generated from optical potentials, which give a good description of the elastic scattering at the same energies, and the calculations were performed on an IBM-704. Both single-particle and collective (surface-coupling) transitions are considered. The results are compared with the adiabatic approximation ($Q=0$), which predicts symmetry about an axis bisecting the incident and scattered directions when spin-flip can be neglected.[1] The circular polarization of the γ rays is also predicted. At lower energies, the direct interaction γ-ray distribution is compared with the predictions of the statistical model of the compound nucleus.

[1] J. S. Blair and L. Wilets, Bull. Am. Phys. Soc. Ser. II, 4, 460 (1959).

VA4. On the Spin Dependence of s-Wave Neutron Strength Functions.* KAMAL K. SETH, *Duke University.*—The question of spin dependence of s-wave neutron strength functions S_J is examined empirically (a) by comparing (Γ_n^0/D) for adjoining even-even ($I=0$) nuclei and odd A ($I\neq 0$) nuclei, (b) by requiring that (Γ_n^0/D) for odd nuclei with different values of I vary smoothly with atomic weight, and (c) by inquiring into the spin dependence of $(\Gamma_n^0)_J$. It is concluded that S_J is proportional to $(2J+1)^{-1}$ or, equivalently, since $D_J\propto(2J+1)^{-1}$, that $(\Gamma_n^0)_J$ is proportional to $(2J+1)^{-2}$. It is suggested that the optical potential should include a term proportional to $\mathbf{I}\cdot\boldsymbol{\sigma}$ which is dependent on target spin $\mathbf{I}$.

* This work is supported by the U. S. Atomic Energy Commission.

VA5. Direct (γ,d) Reaction.* V. A. MADSEN AND E. M. HENLEY, *University of Washington.*—We have examined the direct photodeuteron reaction, using the I. P. M. with a velocity-dependent potential to describe the nucleus and the optical model for the deuteron center-of-mass motion. For electric dipole emission the mechanism can be described as an indirect pickup process in which interference effects play an important role.[1] In particular, for p-shell self-conjugate nuclei in the absence of spin-orbit coupling, but with charge independence and a zero range force between the proton and neutron, this interference results in a differential cross section proportional simply to $1+\cos^2\theta$. Preliminary numerical calculations give a total cross section of the order of 0.5 mb for the $O^{16}(\gamma,d)$ reaction at deuteron energies of the order of 10 Mev. Quadrupole photoemission is negligible at the deuteron energies considered. We expect to present further numerical results for this reaction computed with a Saxon optical potential.

* Supported in part by the U. S. Atomic Energy Commission.
[1] These were neglected by J. Sawicki and W. Csyz, Nuclear Phys. 4, 248 (1957).

VA6. Theory of Average Nuclear Reaction Cross Sections.* P. A. MOLDAUER, *Argonne National Laboratory.*—In the past explicit formulas for average nuclear reaction cross sections have been derived under the assumption that the average channel widths $\langle\Gamma_c\rangle$ are very small compared to the average level spacing D. This assumption often breaks down for neutron channels at optical model maxima even at kilovolt energies. It is shown that the average compound nucleus cross section for entrance channel s and exit channel t with total angular momentum J is given by $\pi\lambda^2 g_J\langle\tau_s\tau_t/\tau\rangle$ (1+higher order terms), where the average value of the resonance parameter $\tau_s=2\pi\Gamma_s D_J^{-1}$ is related to the optical model transmission factor T_s by $T_s=\langle\tau_s\rangle-\frac{1}{4}\langle\tau_s\rangle^2$. This latter relation is shown to be valid if the reduced width amplitudes have random signs and if $\langle\tau_s\rangle<2$. Since $\langle\tau_s\rangle$ approaches the value two as T_s approaches unity, the effect is to enhance strength function peaks compared to transmission factor peaks. The higher order terms, in the continuum region, may approach $(2\pi)^{-1}\langle\tau_s+\tau_t\rangle$ but can be taken into account there by applying the Thomas correction factor to $\langle\Gamma_s\rangle$ and $\langle\Gamma_t\rangle$. The effect of these considera-

tions on neutron capture and on compound elastic and inelastic scattering cross sections is discussed.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

VA7. *K*-Conversion Coefficients of *E2* Transitions. M. K. RAMASWAMY,* *The Ohio State University* (introduced by P. S. Jastram).—The *K*-conversion coefficients of 0^+-2^+ (pure *E2*) transitions in even-even nuclei have been examined. A plot of the ratio $R(\alpha_k)$ of the experimental to the theoretical values of α_k as a function of the mass number *A* indicates a possible systematic dependence on the deformation of the nucleus. For instance, this ratio is less than unity for spherical or near-spherical nuclei, whereas it is much larger than unity for deformed nuclei. This observation, based on a limited number of cases, is in agreement with that of Subba Rao[1] for 2^+-0^+ transitions. It is not to be expected that these deviations can be explained in terms of the usual theory of internal conversion by taking into account the finite nuclear size, since this contribution is presumably far outweighed by the collective enhancement of the *E2* matrix element in even-even nuclei, both near and far from closed shells.

* Supported by the U. S. Atomic Energy Commission.
[1] B. N. Subba Rao, Nuovo cimento **17**, 189 (1960).

VA8. Interaction Strength in Direct Reactions. W. TOBOCMAN,* *Case Institute of Technology*, AND W. R. GIBBS,* *Rice University*.—In attempting to fit experimental deuteron stripping cross sections with the distorted wave Born approximation treatment for direct reactions, we seem to find a trend for the experimental cross section to be roughly four times greater than our calculations predict. The effect also has been noted by L. Rodberg.[1] A similar effect has been noted for inelastic scattering by C. A. Levinson and M. K. Banerjee.[2] Since the fits to the angular distributions appear to be more or less satisfactory, the effect we report would seem to indicate that for some reason the effective nucleon-nucleon interaction that gives rise to a direct reaction is enhanced by about a factor of two.

* Supported in part by the National Science Foundation. On leave from Rice University.
[1] L. Rodberg (private communication).
[2] C. A. Levinson and M. K. Banerjee, Ann. Phys. **3**, 81 (1958).

VA9. Mechanism for the $B^{10}(d,p_1)B^{11*}$ (2.14-Mev) Reaction.† F. S. LEVIN, *University of Maryland and Oak Ridge National Laboratory*.—A Born approximation calculation of the differential cross section for the anomalous stripping reaction $B^{10}(d,p_1)B^{11*}$ has been performed. The reaction mechanism was found to be the target proton interaction, which causes angular momentum recouplings that allow excited B^{10} states to act as parents for B^{11*}. No interaction can bring the B^{10} ground state in as a possible parent.[1] The heavy particle stripping mechanism, which does not account for the behavior of the angular distribution,[2] gives rise to a cross section about 100 times larger than an upper bound on the knock-out cross section.[3] Angular distributions based on the target proton interaction were calculated on the IBM 704 computer at ORNL using $j-j$ coupled wave functions. The energy variation of the angular distribution at angles less than 90° can be interpreted as a deuteron size effect, but more accurate wave functions are required to predict the shape of the angular distributions.

† Supported in part by the U. S. Atomic Energy Commission.
[1] J. E. Bowcock, Phys. Rev. **112**, 923 (1958).
[2] F. Levin and W. MacDonald, Bull. Am. Phys. Soc. Ser. II, **4**, 58 (1959).
[3] A. P. French, Phys. Rev. **107**, 1655 (1957).

VA10. Low *Q*-Value Stripping Reactions. W. R. GIBBS, *Rice University*, AND W. TOBOCMAN,*† *Case Institute of Technology*.—The $C^{13}(dp)C^{13}$ cross section for incident deuteron energy $E_D=2.1$ Mev has been calculated for *Q* values ranging between 4.2 Mev and −0.823 Mev. The calculation was based on the distorted wave Born approximation theory assuming $l=0$ for the captured neutron. Our object was to verify the hypothesis[1] that distortion effects are strongly reduced when $Q\sim-E_{D/2}$. Our results indicate that this is not the case.

* Supported in part by the National Science Foundation.
† On leave of absence from Rice University.
[1] D. H. Wilkinson, Phil. Mag. **3**, 1185 (1958); J. P. F. Sellschop, Phys. Rev. **119**, 251 (1960).

VA11. Numerical Study of Distortion Effects in Deuteron Stripping Reactions. R. H. BASSEL, R. M. DRISKO, AND G. R. SATCHLER, *Oak Ridge National Laboratory*.—Numerical calculations of deuteron stripping have been made using the distorted wave Born approximation.[1] Differential cross sections, polarizations, and γ-ray angular correlations are computed for a variety of energies, *Q* values, and angular momentum transfers of $L=0$ through 4, for typical light, medium, and heavy nuclei. The optical model potentials which best describe the elastic scattering of deuterons and nucleons are used to give "standard" stripping curves. By varying the optical model parameters the sensitivity of these results to changes in the elastic distortions is determined. The main stripping peak is very stable to these changes, while the polarization is much more sensitive. Larger changes are found for reactions on light than on heavy nuclei. By studying the stripping integrals we find the reaction is often strongly localized near the nuclear surface. The calculations were carried out on an IBM-704 computer.

[1] W. Tobocman, Phys. Rev. **115**, 99 (1959).

SATURDAY MORNING AT 9:15

Statler-Hilton, Grand Ballroom

(C. H. TOWNES presiding)

Division of Solid-State Physics: Optical Masers and Related Subjects

W1. Spectra of Transition-Metal Ions in Wurtzite and Zinc Blende. H. WEAKLIEM, *RCA Laboratories*. (30 min.)

W2. Sharp Line Spectra of Chromium in MgO and Al_2O_3 Crystals. A. L. SCHAWLOW, *Bell Telephone Laboratories*. (30 min.)

W3. The Ruby Optical Maser. T. H. MAIMAN, *Hughes Research Laboratory*. (30 min.)

Masers

W4. Coherence Experiments with a Pulsed Ruby Optical Maser. D. F. NELSON, R. J. COLLINS, AND A. L. SCHAWLOW, *Bell Telephone Laboratories.*—Spatial coherence of a light beam can be investigated by causing different parts of a wave front to interfere, e.g., Young's experiment. By taking this approach the coherence of the emission from a pulsed ruby optical maser[1,2] was measured using two slit interference patterns. The maser used in these experiments was similar to that reported earlier[2] except for the inclusion of two slit shaped openings in the silver end coatings. The interference fringes obtained had the expected angular separation and intensity ratios. This and other experiments lead to the conclusion that the maser light is coherent across the end of the rod for distances of hundreds of wavelengths. The fringes disappear below the maser threshold since the normal fluorescence cannot produce interference fringes within this geometry. Structure in the maser emission perpendicular to the main pattern has been observed. The amount of this structure increases as the excitation is increased above the maser threshold. A discussion of the relation of this structure to the crystal perfection and the relaxation oscillations[2] will be given.

[1] T. H. Maiman, Brit. Commun. & Electronics **7**, 674 (1960).
[2] R. J. Collins, D. F. Nelson, A. L. Schawlow, W. Bond, C. G. B. Garrett, and W. Kaiser, Phys. Rev. Letters **5**, 303 (1960).

W5. Monochromaticity and Directionality of Coherent Light from Ruby. C. G. B. GARRETT, W. L. BOND, AND W. K. KAISER, *Bell Telephone Laboratories.*—The light produced by a ruby rod operated as a pulsed optical maser[1,2] has been investigated with a 10-mm Fabry-Perot etalon. The coherent light found to emerge from the end of the rod in an extremely narrow cone. The width of the Fabry-Perot fringes within this cone indicates a line sharpening of nearly two orders of magnitude. Within the resolving power of the etalon (0.05 cm^{-1}), all of the light within the cone possesses the same wavelength and the same line width. Furthermore, in most cases, the wavelength is maintained for the full duration of the phenomenon (5×10^{-4} sec) in spite of the fact that the light is emitted in many short bursts, each about 10^{-6} sec long, rather than continuously. In some experiments, a mosaic structure, having a spacing of the order of 1/100°, also is seen; this phenomenon is not due to gross interference effects but is probably associated with the complex spatial configuration of the coherent field within the ruby.

[1] T. Maiman, Nature **187**, 493 (1960); Brit. Commun. & Electronics **7**, 674 (1960).
[2] R. J. Collins, D. F. Nelson, A. L. Schawlow, W. Bond, C. G. B. Garrett, and W. Kaiser, Phys. Rev. Letters **5**, 303 (1960).

W6. Modulation of Coherent Light. JENNY E. ROSENTHAL, *Bramley Consultants.*—To use an optical maser effectively as a means of transmitting information, the light must be probed time sequentially at every point of information in a wave-front plane. Time sequential modulation of different areas in the cross section of a coherent light beam by maser modulation seems impractical. Ideally, rates of transmission should be comparable to the number of photons per second emitted by the maser. Modulation of the transmitting property of a light valve irradiated by coherent light could partially exploit the possibility of using the spatial distribution of information. A light valve is discussed which uses carrier density modulation of light passing through an epitaxial semiconductor sheet. Speed of presentation of information depends among other factors on position of semiconductor absorption edge and free carrier lifetime. A modulated electron beam injects the carriers into the semiconductor. With this mode of operation, rates of presentation of 10^{10} bits and higher should be realizable. Although readily available semiconductor sheets might serve this purpose in conjunction with a Hughes type optical maser, better results would be obtained if the characteristics of the two components could be matched.

W7. Preliminary Experiments with the Atomic Hydrogen Maser. DANIEL KLEPPNER, H. MARK GOLDENBERG, NORVAL FORTSON, AND NORMAN F. RAMSEY, *Harvard University.*—An experimental upper limit to the frequency shift due to wall collisions in the atomic hydrogen maser has been established by comparing the maser to an atomic beam frequency standard. No measurable change of frequency with the size of the storage bulb was observed, indicating a wall shift of less than one part in 10^9. An exact determination of the wall shift will be possible only when a second maser is available for comparison purposes. Theoretical estimates of the stability and precision of the atomic hydrogen maser indicate that the limit probably will be due either to wall collisions or second-order Doppler shift. The minimum wall shift is estimated to be a part in 10^{13}, based on the results of pressure shifts in optical pumping. The effect of the wall shift on stability should be much less than the magnitude of the shift itself. The temperature dependence of the Doppler shift is about 3 parts in 10^{13} per degree for hydrogen, which indicates a practical upper limit to the stability of about 1 part in 10^{15}.

W8. Maser Action in Optically Pumped Rb^{87}. NORMAN KNABLE, *National Bureau of Standards.*—Maser action is observed in a microwave cavity enclosing a quartz cell which contains Rb^{87} vapor and a buffer gas. 5×10^{-12} w of microwave energy is obtained from the optically pumped vapor at the hyperfine transition frequency with wall losses 10^{-11} w. The bandwidth of the transition is 20 cycles. The opacity of the Rb vapor to the resonance radiation and the saturation characteristics of the hyperfine line are measured for a variety of experimental parameters.

W9. Maser System Normalized Population Distribution Calculated by Method of Partial Distribution. J. D. KEATING, L. E. FOLLIS, AND WILLIAM A. BARKER,* *McDonnell Aircraft Corporation.*—A method of solution for the normalized population distribution and differences of a multilevel maser system has been devised. In this method, the total normalized population of a given level n_i is considered to be the sum of a number of competing transition processes, each of which results in a partial population distribution. The relative contribution to the total population of each of the competing processes is determined by a weighting factor, f_j, which is a function of the thermal and radiative transition probabilities. The viewpoint is analogous to that of a chemical system of r competing chemical reactions, each of which reacts to give a partial distribution of β end products, with each of the reactions contributing $f_j(j=1, 2, \cdots, r)$ mole fractions to the total of each of the β end products. The normalized population distributions of a three-level system and a four-level system calculated by this method have been determined to be identically equal to the distributions normally found by solution of the rate equations. The four-level system will be discussed in detail.

* St. Louis University, Consultant to McDonnell Aircraft Corporation.

SATURDAY AFTERNOON AT 1:30

New Yorker, Grand Ballroom

(CONYERS HERRING presiding)

Division of Solid-State Physics: Invited Papers

WA1. Recent Studies of Tunneling in Semiconductor Diodes. L. ESAKI, *IBM Research Laboratory.* (30 min.)

WA2. Electron Tunneling into Superconductors. L. GIAEVER, *General Electric Research Laboratories.* (30 min.)

WA3. Magneto-Optic Exciton Spectra and Band Structure of CdS. D. G. THOMAS, *Bell Telephone Laboratories.* (30 min.)

WA4. Nuclear Magnetic Resonance and Magnetic Ordering in NiF_2. R. G. SHULMAN, *Bell Telephone Laboratories.* (30 min.)

SATURDAY AFTERNOON AT 1:30

Statler-Hilton, Penn Top South

(H. PALEVSKY presiding)

Neutrons II

X1. Neutron Resonance Parameters in the kev Region.* EDWARD G. BILPUCH, KAMAL K. SETH, CHARLES D. BOWMAN, AND H. W. NEWSON, *Duke University.*—We have analyzed about 200 resonances observed in total neutron cross sections of $Cl^{35,37}$, $Ca^{40,44}$, $Cr^{50,52,54}$, $Fe^{54,56}$, $Ni^{58,60}$, Sr^{88}, Y^{89}, Te^{130}, $Ba^{136,138}$, and $Pb^{206,207,208}$. These cross sections were measured with our 122° and 160° collimators over the energy range 1 to 200 kev. Most of the above nuclei are even-even and in addition are either magic in their proton or neutron number or fairly close to being so. Γ_n^0, D, and (Γ_n^0/D) for these nuclides are presented, and the distributions of Γ_n^0 and s (the local spacing) also are discussed.

* Supported in part by the U. S. Atomic Energy Commission.

X2. High-Resolution Neutron Spectroscopy up to 650 kev.* CHARLES D. BOWMAN, EDWARD G. BILPUCH, ROBERT H. TABONY, AND H. W. NEWSON, *Duke University.*—The neutron total cross section of the separated isotopes of even-even nuclei in the range of $A=50$ has been studied with high resolution using the $Li^7(p,n)Be^7$ reaction as the neutron source. The measurements were made with neutron spread less than 1 kev over most of the energy range from 80–650 kev. The isotopes Ca^{40}, Cr^{52}, Fe^{54}, and Fe^{56} are characterized by a number of narrow higher angular momentum resonances superimposed on much wider $l=0$ resonances. The Ti^{46}, Ti^{48}, and Ti^{50} isotopes exhibit a much larger proportion of higher angular momentum resonances than the other nuclides so that $l=0$ assignments are less definite. In all the nuclei $l=0$ resonance widths are difficult to determine with much accuracy by means of single level area analysis because of the strong interference with neighboring resonances. A multi-level formula derived from R-matrix theory has been used to fit the data. Comparisons of the experimental and theoretical curves will be given. The distributions of widths and level spacings also will be presented.

* Supported in part by the U. S. Atomic Energy Commission.

X3. Resonance Capture Gamma Rays from Pt^{196}.* R. E. CHRIEN, H. H. BOLOTIN, AND H. PALEVSKY, *Brookhaven National Laboratory.*—The radiation resulting from neutron resonance capture in a Pt target has been studied at the BNL fast chopper facility at the NRU reactor at Chalk River. Gamma-ray spectra from 6.2 to 8.5 Mev, in 16 pulse-height channels, from an array of 6 NaI detectors has been obtained for each resonance. Interest has been directed towards the 14 resonances of Pt^{195} present up to 300 ev. The transition probabilities for the ground-state transition are found to exhibit greater fluctuations than had been observed in U^{238}.[1] Data also will be presented concerning the transitions from the capturing state to the first and second excited states of Pt^{196}, and the results will be compared to those reported by other experimenters.[2,3]

* Work carried out under the auspices of the U. S. Atomic Energy Commission.

[1] Hughes, *et al.*, *Proceedings of the International Conference on Nuclear Structure* (University of Toronto Press, Toronto, 1960), p. 771.

[2] J. R. Bird and J. R. Waters, J. Nuclear Energy **14**, 212 (1959).

[3] L. M. Bollinger, R. E. Coté, and T. J. Kennett, Phys. Rev. Letters **3**, 376 (1959).

X4. Temperature Dependence of Neutron Resonant Shapes.* H. E. JACKSON, L. M. BOLLINGER, AND R. E. COTÉ, *Argonne National Laboratory.*—Measurements of the shape of the neutron-capture resonance in U^{238} at 6.6 ev as a function of temperature have been extended to liquid helium temperatures. Calculations based on the Lamb model[1] with the asymptotic expansion of Nelkin and Parks[2] indicate that the line shapes predicted by the complete Lamb model and by the effective-temperature approximation should be measurably different. The experimentally observed shift in the transmission minimum as the temperature is lowered is consistent with the description of the target nuclei as bound in a simple Debeye lattice with $\theta=200°K$. Moreover the peak cross section at $T=4.3°K$ is in agreement with the complete Lamb model and in disagreement with the effective-temperature approximation. Measurements with a natural foil and U_3O_8 will be compared.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] W. E. Lamb, Phys. Rev. **55**, 190 (1939).

[2] M. Nelkin and D. E. Parks, Phys. Rev. **119**, 1060 (1960).

X5. Neutron Resonances in Zirconium and Arsenic. W. C. OLSEN AND P. P. SINGH, *Atomic Energy of Canada Limited.*—The BNL Chopper, installed at the NRU reactor, Chalk River,

has been used, with an 88-m flight path, to study the neutron transmission of zirconium and arsenic. Zirconium is of a special interest to reactor technologists and is also of some interest to physicists. In the energy region up to 20 kev, 14 resonances were observed using natural zirconium samples. The well-known resonance at 300 ev is found to be a doublet, 295 ev and 303 ev. Samples enriched in Zr^{91}, Zr^{92}, and Zr^{94} were used to identify the resonances. The neutron widths and the total widths of the resonances, computed by the method of area analysis, will be presented along with the total neutron cross sections as a function of neutron energy. Transmission measurements on arsenic samples have revealed 16 resonances in the energy range from 200 ev to 4 kev. The parameters of these resonances will be presented along with derived strength function. Of these resonances in As, eight have been reported previously while resonance parameters of five were known.

X6. Spins of Neutron Resonances in Pu^{239} from Scattering Measurements. J. S. FRASER* AND R. B. SCHWARTZ,† *AERE, Harwell.*—Measurements of neutron scattering[1] from Pu^{239}, using the Harwell 28-Mev linear electron accelerator, have been extended to some of the higher energy levels. After correction for the contribution of fission neutrons, the values of $\sigma_0\Gamma_n$ for the scattering resonances were combined with published total cross-section measurements to give the statistical weight factors g hereunder.

E_0 (ev)	$\sigma_0\Gamma_n$ (ev-barns)	g	J (assigned)
7.8	2.1± 0.8	0.82±0.31	1
10.9	3.4± 1.1	0.72±0.23	1
11.9	3.3± 1.1	0.67±0.22	1
14.7	16.3± 2.6	0.37±0.06	0
17.6	3.4± 1.9	0.72±0.4	1
22.2	14.7± 4.5	0.20±0.06	0
41.4	23.2± 6.1	0.76±0.2	1
44.5	63 ±15	0.42±0.1	0

* Now at Atomic Energy of Canada Limited, Chalk River, Ontario.
† Now at Brookhaven National Laboratory, Upton, Long Island, New York.
[1] J. S. Fraser and R. B. Schwartz, Bull. Am. Phys. Soc. Ser. II, 5, 294 (1960).

X7. Analysis of Breit-Wigner Resonances Using the IBM 704 Computer. J. A. HARVEY AND S. E. ATTA, *Oak Ridge National Laboratory.*—Two codes have been written for the IBM 704 computer in order to obtain parameters of Breit-Wigner resonances from transmission data. The first code is an area analysis code which determines the neutron widths of the resonances for assumed total widths. The second code is a shape fit code (used when the Doppler and resolution widths are $\lesssim$ the total widths of the resonances) which determines the resonant energies, the total widths, and the neutron widths of the resonances. Both codes assume that the cross section can be represented by the sum of single-level Breit-Wigner formulas, with interference between resonance and potential scattering but no interference between resonances; that the Doppler broadening is Gaussian; and that the resolution can be represented by a Gaussian. For the area analysis code, the transmission is analyzed in groups, with no more than 12 resonances in any group. The cost to analyze a typical 1024-channel transmission run with ~30 resonances is ~$100. The shape analysis solves for the parameters Γ, E_0, and Γ_n for as many as 4 resonances at once by the least-squares method for ~$40.

X8. High-Resolution Total Cross Section Measurements on Np^{237} and Am^{241} Using the ORNL Fast Chopper.* G. G. SLAUGHTER, J. A. HARVEY, AND R. C. BLOCK, *Oak Ridge National Laboratory.*—The ORNL fast chopper and associated 180-m flight path were utilized in measuring the total cross sections of Np^{237} (from 10 to 86 ev) and Am^{241} (from 5.4 to 25 ev) with ~0.2% energy resolution. Data were analyzed using an IBM 704 area analysis code[1] which computes the neutron widths of resonances for an assumed total width. This code also convolutes Doppler and resolution shapes with the line shape in calculating a transmission which is compared with the observed transmission. Resonance parameters, level spacings, and strength functions will be presented.

* This work supported by the U. S. Atomic Energy Commission.
[1] See preceding abstract.

X9. Multilevel Fit to the Total Neutron Cross Section of Vanadium up to 25 kev. J. E. LYNN,* F. W. FIRK,† AND M. C. MOXON, *AERE, Harwell* (introduced by J. A. Harvey).—The total neutron cross section of V^{51} has been measured up to 25 kev using the Harwell 30-Mev linear electron accelerator with a resolution of 3 nanosec m^{-1}. A multilevel fit to the first six levels in $V^{51}+n$ has been made using the Thomas[1] approximation of the general Wigner-Eisenbud formalism of nuclear reaction theory. The resonances at 4.2, 16, and 22 kev have been assigned total spins $J=4$ and those at 6.7, 11.4, and 17 kev assigned $J=3$.

* Now visiting Argonne National Laboratory, Argonne, Illinois.
† Now visiting Oak Ridge National Laboratory, Oak Ridge, Tennessee.
[1] R. G. Thomas, Phys. Rev. 97, 224 (1955).

X10. Thermal Neutron Activation Cross Sections of Hf^{174} and Te^{130}. L. J. ESCH AND W. E. MOORE, *Knolls Atomic Power Laboratory.**—The hafnium-174 cross section has been measured relative to that of gold by an activation and gamma counting technique. A sample of HfO_2, 18.5% enriched in Hf^{174}, was dissolved in hydrofluoric acid and co-precipitated with Al_2O_3 to minimize self-shielding. The mixture was irradiated along with the gold standard in the Thermal Test Reactor and counted using a NaI(Tl) crystal and a 128-channel pulse-height analyzer. The ratio of the intensities of the Hf^{175} 343-kev and Au^{198} 411-kev gamma rays was taken as a measure of the ratio of cross sections. A correction was applied to the measured cross section to take into account the neutron energy spectrum of the TTR. The 2200 m/sec cross section thus obtained is 390±55 barns. A similar analysis has been made on a sample of natural tellurium, measuring the intensity of the Te^{131} 573-kev gamma ray relative to the I^{131} 364- and 637-kev gamma rays; the latter activity arises via the well-known Te^{130} capture cross section. The thermal activation cross section for production of 17-day Te^{131} is 2.4±1.0 barns. This decay was followed for 100 days, allowing an upper limit of 1 barn to be placed on the cross section for production of 154-day Te^{121}.

* Operated by the General Electric Company for the U. S. Atomic Energy Commission.

X11. Total Neutron Cross Sections of Dysprosium-164, Dysprosium, and Hafnium. W. E. MOORE, *Knolls Atomic Power Laboratory.**—Transmission measurements have been made on samples of natural dysprosium, and dysprosium enriched to 90% Dy^{164}, and a metallic sample of natural hafnium. The dysprosium samples were prepared by uniformly mixing pure Dy_2O_3 with aluminum powder; "blank" samples containing Al_2O_3 and aluminum powder were prepared in the same manner in order to account for extraneous scattering and absorption. A slow-speed flat-plate chopper was used to interrupt a well-collimated thermal neutron beam; energy analysis was accomplished by timing the neutron flight over an evacuated 6-m path. Data obtained for natural dysprosium indicate $1/v$ behavior over the range 0.001 to 0.4 ev, to within 15% at the extremities, which represents the magnitude of the experimental error there. There is a significant variation from previous work[1] which had indicated non-$1/v$ behavior above 0.1 ev. Data obtained using enriched Dy^{164} indicate $1/v$ behavior over the range 0.0006 to 0.1 ev, to within 10% at

the extremities. Data will be presented extending these results to 1 ev in order to resolve this discrepancy. The hafnium cross section exhibits $1/v$ behavior over the range 0.0006 to 0.04 ev.

* Operated by the General Electric Company for the U. S. Atomic Energy Commission.
[1] W. J. Sturm, Phys. Rev. 71, 757 (1947).

X12. Inelastic Scattering of Slow Neutrons from Methane.* P. D. RANDOLPH, K. A. STRONG, AND R. M. BRUGGER, *Phillips Petroleum Company.*—Monoenergetic slow neutrons from the MTR phased rotor velocity selector have been scattered from samples of methane gas at room temperature. Measurements were made of the absolute scattering cross section, differential in energy and angle, for seven scattering angles (16° to 84°) at five incident neutron energies (0.015, 0.025, 0.07, 0.1, 0.14 ev). These cross sections were converted to the scattering law.[1] If it is assumed that the molecules of the gas have an effective mass of 3.22 hydrogen masses (the average value predicted using the Sachs-Teller[2] mass tensor), the results are in agreement with the scattering law for an ideal gas over most of the range of momentum transfers measured. At the larger values of momentum transfer the effect of the vibrational states in methane reduce the scattering law below that of an ideal gas. Extrapolation of the scattering law yields the frequency distribution.[1] By comparing the experimental results with the ideal gas, it is shown that data at very small momentum changes are needed to give valid frequency distributions.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] P. A. Egelstaff, IAEA Symposium on Inelastic Scattering of Neutrons in Solids and Liquids, Vienna (October, 1960).
[2] R. G. Sachs and E. Teller, Phys. Rev. 60, 18 (1941).

X13. Scattering of Cold Neutrons by Ice.* R. L. STEARNS,† H. R. MUETHER,‡ AND H. PALEVSKY, *Brookhaven National Laboratory.*—The spectrum of beryllium filtered neutrons scattered at 90° by 0.008-in. samples of ice at −7°C has been measured using the Brookhaven slow chopper apparatus. A sharp peak is observed at a neutron energy of 76 mv, corresponding to an optical vibration of 71 mv. A broad spectrum of neutrons with energy gains up to 50 mv also is observed and is attributed to acoustic vibrations and possible lower energy optical vibrations. This spectrum gives a phonon frequency distribution for ice that increases approximately as the square of the phonon energy up to 5 mv, exhibits broad maxima at 6.5 and 35 mv, and falls off rapidly at 50 mv. These measurements will be compared to similar measurements made on liquid samples.

* Work carried on under the auspices of the U. S. Atomic Energy Commission.
† Permanent address: Vassar College.
‡ Permanent address: State University of New York, Long Island Center.

SATURDAY AFTERNOON AT 1:30

New Yorker, New Orleans Room

(HANS MARK presiding)

Beta and Gamma Spectroscopy II

XA1. Decay of La^{135}.* H. A. GRENCH† AND S. B. BURSON, *Argonne National Laboratory.*—Because of the limited amount of work previously done, the decay scheme of La^{135} (19.8 hr) has been studied extensively mainly by the use of scintillation coincidence spectrometry. The suggested[1] decay scheme with levels in Ba^{135} at 0, 218, 268, 481, 588, and 862 kev has been largely verified. In addition to a 367±3-kev transition between the 588- and 218-kev levels a 376±3-kev radiation has been found to feed the 481-kev level. A lower limit of 5000 has been placed on the K/β^+ ratio to the ground state of Ba^{135}.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Now at Lockheed Missiles and Space Division, Palo, Alto, California.
[1] A. C. G. Mitchell, C. B. Creager, and C. W. Kocher, Phys. Rev. 111, 1343 (1958).

XA2. Disintegration of Ba^{140}. J. S. GEIGER, R. L. GRAHAM, AND G. T. EWAN, *Chalk River Laboratories.*—The decay of Ba^{140} is being studied using the Chalk River $\pi\sqrt{2}$ β-ray spectrometer and coincidence counting techniques. The conversion electron spectrum has been studied at momentum resolutions of 0.1% and 0.06.% Conversion lines are observed corresponding to transitions in La of 13.85±0.05 ($M1$, <0.1% $E2$), 29.97 ±0.05 ($M1$, <0.1% $E2$), 118.8±0.1, 132.7±0.1, 162.7±0.1 ($M1$, <2% $E2$), 304.9±0.1, 423.8±0.2, 437.6±0.2, and 537.3 ±0.2 kev. The relative accuracy of these measurements varies from 0.03 kev for the low-energy lines to 0.1 kev for those of higher energy. The multipolarity assignments result from comparison of the observed conversion electron subshell intensity ratios with the theoretical values of Sliv. The $M1$ character found for the 162.7-kev transition is not consistent with the angular correlation measurement of Kelly and Wiedenbeck. The 537.3-kev γ transition is coincident with L conversion electrons of both the 13.85- and 29.97-kev transitions. The La^{140} level sequence established from energy sum considerations, conversion electron-gamma and gamma-gamma coincidence measurements is 0 kev (3−), 29.97 kev (2−), 43.84 kev (1−), 162.7 kev (2−), 467.6 kev (1−), and 581.1 kev (0−). These spin and parity assignments are not uniquely determined. This investigation establishes experimentally the 13.85-kev transition originally hypothesised by Cork *et al.* and repositions the 537.3-kev transition in the level sequence.

XA3. Angular Distribution of Beta Radiation from Oriented Ce^{141}. D. D. HOPPES, E. AMBLER, R. W. HAYWARD, AND R. S. KAESER, *National Bureau of Standards.*—Measurements have been made on the 30% abundant, first forbidden, $\Delta J=1$, 585 kev, ground-state beta transition to Pr^{141} from cryogenically oriented Ce^{141}. The beta radiation from the Ce^{141} source, grown in the uppermost surface of a neodymium-ethylsulfate crystal employed for orienting purposes, is detected by an anthracene scintillator, which provides the input for a 100-channel pulse-height analyzer. Three NaI gamma counters located equatorially 15 cm from the axis of the oriented nuclei monitor the gamma rays following the inner 440-kev beta transition to the first excited state in Pr^{141}. Coincidences between the beta and gamma radiation allow separation of the inner beta group. The orientation parameters f_k are determined from the gamma-ray anisotropy. The experimentally determined distribution for the ground-state transition is

$$W(\vartheta)/N_0 = 1-(1.11\pm0.10)(p/E)f_1P_1(\cos\vartheta) + (0.36\pm0.10)(p^2/E)f_2P_2(\cos\vartheta),$$

where the numerical coefficients are determined at an average energy 1.85 mc^2.

XA4. Nuclear Matrix Elements in the Forbidden Beta Decay of Ce^{141}. R. W. HAYWARD, E. AMBLER, D. D. HOPPES,

AND R. S. KAESER, *National Bureau of Standards.*—The energy and angular distribution of beta particles from oriented Ce^{141} allows one, in principle, to determine the relative values of the four contributing first-forbidden (real) nuclear matrix elements. In practice, however, the insensitiveness of the energy dependence allows a determination of the relative values only after one ratio has been fixed by theory. By taking into account all possible shell-model configurations for Ce^{141} and Pr^{141} one finds that two ratios can be fixed uniquely and independently of any details of the radial wave functions. This method of analysis allows the determination of the ratios $M(i\mathbf{r})/M(\boldsymbol{\sigma}\times\mathbf{r})=-1$, $M(iB_{ij})/M(\boldsymbol{\sigma}\times\mathbf{r})=-1.9$, and $M(\boldsymbol{\alpha})/M(\boldsymbol{\sigma}\times\mathbf{r})=-37\pm1.5$. These values are based on the use of lepton wave functions expanded in powers of $\alpha Z/2R$. An analysis is in progress using exact lepton wave functions and taking into account nuclear finite size effects. The ratio $M(\boldsymbol{\alpha})/M(\boldsymbol{\sigma}\times\mathbf{r})$ is of particular interest since a radial integral containing a gradient of a nuclear wave function is involved.

XA5. Gamma-Gamma Directional Correlations in Cs^{133}.* ATAM P. ARYA, *Pennsylvania State University.*—Directional correlation measurements have been made on the 356—82-kev, 301—82-kev, and 80—82-kev gamma-gamma cascades in Cs^{133} following the decay of 8-yr half-life Ba^{133} with a coincidence scintillation spectrometer using NaI detectors. The observed correlation functions are

$$W(\Theta)=1+(0.042\pm0.005)P_2(\cos\Theta)-(0.0041\pm0.0038)P_4(\cos\Theta),$$

$$W(\Theta)=1-(0.0257\pm0.011)P_2(\cos\Theta)-(0.0002\pm0.008)P_4(\cos\Theta),$$

and

$$W(\Theta)=1+(0.0487\pm0.017)P_2(\cos\Theta)+(0.0011\pm0.012)P_4(\cos\Theta),$$

respectively, for the three cascades. These gamma-gamma directional correlations were found to be consistent with the spin assignments of $\frac{7}{2}^+$, $\frac{5}{2}^+$, $\frac{3}{2}^+$, $\frac{3}{2}^+$, and $\frac{1}{2}^+$ to the levels at the ground state, 82 kev, 162 kev, 383 kev, and 438 kev in Cs^{133}. The probable assignment of the multipolarities for different gamma rays is as follows: The 356-kev gamma ray is pure $E2$. The 82-kev gamma ray is a mixture of $(96.5\pm0.5)\%$ $M1$ and $(3.5\pm0.5)\%$ $E2$. The 301-kev gamma ray has a mixture of either $(98.5\pm1.0)\%$ $M1$ and $(1.5\pm1.0)\%$ $E2$ or $(6\pm2)\%$ $M1$ and $(94\pm2)\%$ $E2$. The 80-kev gamma ray has a mixture of either $(82\pm6)\%$ $M1$ and $(18\pm6)\%$ $E2$ or $(2.0\pm1.5)\%$ $M1$ and $(98.0\pm1.5)\%$ $E2$.

* This work was supported in part by the U. S. Atomic Energy Commission.

XA6. Beta-Gamma Angular Correlation in the Decay of Eu^{154}.* R. G. WILKINSON, K. S. R. SASTRY, AND R. F. PETRY, *Indiana University.*—The directional correlation between the first forbidden nonunique outer beta-ray group of Eu^{154} and the 0.123-Mev cascade gamma ray in Gd^{154} has been measured at ten beta-ray energies with an accuracy of about 5%. Magnetic analysis of the beta rays was employed with 5% transmission and 5% energy resolution. The measured anisotropy coefficient ϵ ranges from 0.10 to 0.17 in the energy interval 0.80 to 1.60 Mev. These results are quite different from those obtained in the parallel case of Eu^{152}. It will be shown that the "modified B_{ij} approximation" of the theory of Kotani and Ross[1] does not apply. An analysis of the data leads to values of the matrix element ratios Y, u, and x (Kotani's notation) which are consistent with Langer's measured shape factor.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

[1] T. Kotani and M. Ross, Progr. Theoret. Phys. (Kyoto) **20**, 643 (1958).

XA7. Conversion Electron Spectrum of Tb^{161}. R. L. GRAHAM, J. S. GEIGER, AND G. T. EWAN, *Chalk River Laboratories.*—The conversion electron spectrum in Dy^{161} following β decay from Tb^{161} (7 days) is being investigated at $\sim0.1\sqrt{2}$ momentum resolution using the Chalk River iron-free $\pi\sqrt{2}$ β-ray spectrometer. The internal conversion lines so far observed correspond to transitions of 25.62 ± 0.05 kev ($E1$), 28.69 ± 0.05 kev ($M1$), 43.77 ± 0.05 (96% $M1+4\%$ $E2$), 48.88 ± 0.05 kev (99.6% $M+\sim0.4\%$ $E2$), 57.15 ± 0.05 kev (97% $M1+3\%$ $E2$), 74.50 ± 0.06 kev ($E1$), 77.37 ± 0.06 kev (53% $M1+47\%$ $E2$), and 106.06 ± 0.07 kev ($\sim60\%$ $M1+\sim40\%$ $E2$). The quoted energy errors include an allowance for calibration and systematic errors; the internal consistency in energy is ±0.02 kev. The multipolarity assignments are derived by comparing the experimental L subshell ratios with the theoretical values of Sliv. These results taken together with those of most earlier workers are consistent with levels in Dy^{161} at 0 kev ($5/2+$), 25.62 kev ($5/2-$), 43.77 kev ($7/2+$), 74.50 kev ($3/2-$), 102.98 kev ($7/2-$), and 131.65 kev ($5/2-$). The complexity of conversion lines reported by Baranov *et al.*[1] is not confirmed. We find no evidence for their tentative levels at 48.9 kev and 83.9 kev.

[1] S. A. Baranov, F. Rodinov, G. V. Shiskin, and L. V. Chistiakov, Soviet Phys.—JETP **7**, 946 (1958).

XA8. Decay of $_{68}Er^{172}$ to Excited States in $_{69}Tm^{172}$.* R. G. HELMER AND S. B. BURSON, *Argonne National Laboratory.*—The radioactive nuclide $_{68}Er^{172}$ was produced by double neutron capture in erbium oxide enriched in Er^{170}. The activations were carried out in the Materials Testing Reactor at Arco, Idaho. In addition to three erbium activities and the Tm^{172} daughter, these samples contained six active contaminants. The erbium was separated from the contaminants as well as the daughter by use of an ion-exchange column. Scintillation studies were conducted with a 256-channel coincidence scintillation spectrometer. These measurements indicate the presence of at least eight gamma-ray transitions. Two of these transitions are manifested only by radiations whose energies are indistinguishable from those of K x rays of thulium; i.e., each of these transitions is either highly K converted or the transition energy is approximately 50 kev. The energies of the other six transitions are about 610, 450, 410, 200, 160, and 125 kev. Beta-gamma coincidence experiments indicate the presence of two beta-ray components at approximately 310 and 370 kev. The level scheme deduced for Tm^{172} has excited states at 410, 450, 530, and 610 kev. Another level near 450 kev also may exist.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

XA9. L to K Ratio in the Electron Capture Decay of Ta^{179}.* R. C. JOPSON, HANS MARK,† C. D. SWIFT, AND J. H. ZENGER, *Lawrence Radiation Laboratory, Livermore.*—The L to K electron capture ratio of Ta^{179} has been measured. Thin (0.05-in.) NaI(Tl) scintillation crystals with 0.002-in. Be windows were used to count both the K and the L x rays. Partial fluorescent yields of the L subshells of Hf also were obtained from the coincidence rate between the K and L x rays. From these measurements, the L to K electron capture ratio of Ta^{179} is computed to be 0.59 ± 0.14. The total decay energy for this isotope obtained from this result is approximately 120 kev. This energy is consistent with the observation that no gamma rays accompany the decay of Ta^{179} since the first excited level of Hf^{179} has an energy (122 kev) exceeding the total decay energy of Ta^{179}. The L to K ratio obtained here is about a factor of two smaller than the most recent measurement[1] of this ratio.

* Work supported by the U. S. Atomic Energy Commission.
† Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts.
[1] Bisi, Zappa, and Zimmer, Nuovo cimento **4**, 307 (1956).

XA10. Decay Scheme and L to K Electron Capture Ratio of W^{181}.* J. H. ZENGER, C. D. SWIFT, HANS MARK,† AND R. C. JOPSON, *Lawrence Radiation Laboratory, Livermore.*—The

methods of the foregoing abstract have been used to measure the L to K ratio of W^{181} and the partial flourescent yields of the L subshells of Ta. The L to K ratio is 0.29 ± 0.08 resulting in a decay energy of approximately 200 kev. Two weak (0.2%) gamma rays with energies of 137 kev and 152 kev accompany the decay. These lines decay at the same rate as the x rays, and they are both in coincidence with the L x rays but not with the K x rays. If the gamma rays result from energy levels in Ta^{181}, the decay energy of W^{181} must be between 160 kev and 220 kev in agreement with the L to K ratio result. The present measurements disagree with the most recent value of the L to K ratio[1]; however, the energy levels reported here have been observed previously.[2]

* Work supported by the U. S. Atomic Energy Commission.
† Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts.
[1] Bisi, Terrani, and Zappa, Nuovo cimento 1, 651 (1955).
[2] J. M. Cork, W. H. Nester, J. M. Le Blanc, and M. K. Brice, Phys. Rev. 92, 119 (1953); and Debrunner, Heer, Kundig, Ruetschi, and Lindquist, Helv. Phys. Acta 29, 432 (1956).

XA11. Mass Spectrometric Identification of Long-Lived Tb^{157}, Tb^{158}, Ho^{163}, Hf^{182}.* R. A. NAUMANN† AND M. C. MICHEL, *Lawrence Radiation Laboratory*, AND J. L. POWER, *Princeton University*.—Enriched oxide samples of dysprosium 156, erbium 162, and hafnium 180 have been irradiated at the Materials Testing Reactor in thermal fluxes of approximately 3×10^{14} neutrons/cm²/sec. After a two-month exposure, the rare earth samples were chemically separated by cation-exchange chromatography and the various fractions mass-analyzed. The terbium isolated from the dysprosium sample showed terbium 157, 158, 159 as major and terbium 160 as minor components. The holmium isolated from the erbium sample showed holmium 163 and 165 as major and holmium 166 as minor components. Scintillation spectroscopy of the terbium fraction showed enhanced K-X and 970-kev radiations; the latter ascribed to terbium 158. The holmium fraction examined with an internal gas-proportional counter revealed enhanced electrons of approximately 1 kev, indicative of M-capture in holmium 163. After 6 months' irradiation and chemical purification, the hafnium sample showed the presence of hafnium-182 to the extent of 0.072 ± 0.0036 atom percent. Tantalum 182 was isolated from the hafnium fraction 280 days after purification, indicating a half-life of $8\pm5\times10^6$ yr for hafnium-182.

* Supported in part by the U. S. Atomic Energy Commission.
† Procter and Gamble Faculty Fellow on leave from Princeton University.

XA12. Identification of Neutron-Deficient Iridium Isotopes: Ir^{182}, Ir^{183}, and Ir^{184}.* R. M. DIAMOND, J. M. HOLLANDER, D. J. HOREN, AND R. A. NAUMANN, *Lawrence Radiation Laboratory, Berkeley*.—The Berkeley Heavy-Ion Linear Accelerator (HILAC) has been used to produce the new neutron deficient iridium isotopes Ir^{182}, Ir^{183}, and Ir^{184}. By means of timed chemical separation experiments, NaI scintillation spectrometers, and proportional counters, half-lives have been determined as follows: Ir^{182} (15 ± 1 min), Ir^{183} (58 ± 7 min), and Ir^{184} (3.2 ± 0.2 hr). Evidence also has been found for an isomer in Ir^{183}. The gamma-ray spectra of Ir^{182} and Ir^{184} are very complex, each extending above 4 Mev. Positron branches also are seen in both isotopes. Studies of the gamma-ray spectra indicate that the energies of the first and second excited states of Os^{182} are slightly *higher* than the corresponding states in Os^{184}, which suggest a maximum in the moment of inertia at Os^{184}.

* This research was sponsored by the U. S. Atomic Energy Commission.

XA13. Decay of Re^{184} Isomers. NOAH R. JOHNSON, *Oak Ridge National Laboratory*.*—Both natural rhenium and enriched Re^{185} have been irradiated in a reactor to form Re^{184} by an $(n,2n)$ reaction. The Re^{184} decay followed with an end-window proportional counter was complex with periods of 34 ± 5 days and 165 ± 8 days. In the source prepared from natural rhenium there is an additional weak component with about an 8-yr half-life which is thought to result from Re^{189} formed by double neutron capture. Gamma-ray spectra taken with a NaI spectrometer over a period of about 4 yr showed photopeaks at 0.059, 0.111, 0.162, 0.218, 0.252, 0.320, 0.385, 0.540, 0.640, 0.791, 0.897, and 1.15 Mev. Each of these peaks had a complex decay involving half-lives of about 30 and 170 days. Gamma-gamma coincidence measurements have been made for the peaks at 0.252, 0.320, 0.540, 0.111, 0.791, and 0.897 Mev. The measurements for the latter three peaks were taken at first on a fresh source and then repeated after most of the 30-day component had decayed in order to determine the change in population of W^{184} levels by Re^{184}. These data have led to a level scheme similar to that proposed by Gallagher, Strominger, and Unik.[1]

* Operated by Union Carbide Corporation for the U. S. Atomic Energy Commission.
[1] C. J. Gallagher, Jr., D. Strominger, and J. P. Unik, Phys. Rev. 110, 725 (1958).

SATURDAY AFTERNOON AT 1:30

New Yorker, Terrace Room

(P. KUSCH presiding)

Invited Paper

Y1. Double Nuclear-Resonance Spectroscopy of Rare Spins. E. L. HAHN, *University of California, Berkeley*. (30 min.)

Hyperfine Structure; Nuclear Spins

Y2. Nuclear Spin O^{15} ($\tau_{\frac{1}{2}}=124$ sec).* E. D. COMMINS† AND H. R. FELDMAN, *Columbia University*.—The nuclear spin of O^{15} has been determined to be $1=\frac{1}{2}$ by the atomic beam magnetic resonance method. This value is consistent with that predicted from the nuclear shell model and with previous nuclear data.[1] The O^{15} is produced continuously in the reaction $N^{14}(d,n)O^{15}$ by bombardment of an N_2 gas target with the 5-Mev deuteron beam of the Columbia Van de Graaff accelerator. O^{15}-bearing molecules are dissociated in the source of the beam apparatus by a microwave discharge at 2460 Mc/sec, and the resulting atomic beam is detected by observing the positron decay of the atoms collected on a barium surface. The nuclear spin was determined by measuring the ratios of the frequencies of the Zeeman transitions in the ($^3P_2$) ground

state of O^{16} to the frequency of the Zeeman transition in the ($^3S_1$) metastable state of He^4. Work is continuing in an effort to determine the hfs of O^{18}.

* Work supported by the Office of Naval Research.
† Present address: Department of Physics, University of California, Berkeley 4, California.
[1] D. Strominger, J. M. Hollander, and G. T. Seaborg, Revs. Modern Phys. 30, 585 (1958).

Y3. Hyperfine Structure of the $^3P_1$ State of Mg^{25}. A. G. BLACHMAN AND ALLEN LURIO, *IBM Watson Laboratory.*—The hyperfine structure of Mg^{25} ($I=\frac{5}{2}$) in its metastable $^3P_1$ atomic state has been measured by the atomic beam magnetic resonance method. A beam of Mg atoms in the ground $^1S_0$ state is bombarded by electrons just after they emerge from the oven. This excites a measurable fraction of these atoms to the $^3P_1$ state. Detection is accomplished by electron ejection when the atom in its metastable state is de-excited on a Cs coated surface. The two hyperfine structure intervals were measured and are

$$\Delta\nu(\tfrac{7}{2},\tfrac{5}{2}) = 516.140 \pm 0.010 \text{ Mc/sec},$$
$$\Delta\nu(\tfrac{5}{2},\tfrac{3}{2}) = 350.987 \pm 0.010 \text{ Mc/sec}.$$

From these measured intervals the dipole and quadrupole coupling constants are computed to be

$$a = -145.110 \pm 0.003 \text{ Mc/sec},$$
$$b = -7.858 \pm 0.010 \text{ Mc/sec}.$$

Second-order perturbation between the ^3P fine structure states has not been included. From the b coefficient the quadrupole moment of Mg^{25} is computed to be $Q=+0.14\times10^{-24}$ cm^2 in excellent agreement with previous results.[1] The detection of a beam of atoms in the $^3P_1$ state places a lower limit of approximately 1 msec on the lifetime of this state.

[1] A. Lurio, Bull. Am. Phys. Soc. Ser. II, 4, 419 (1959).

Y4. Hyperfine Structure of $_{36}Kr^{83}$ in the Metastable $^3P_2$ State.* W. L. FAUST, C. L. SUMMERS, AND L. Y. CHOW CHIU, *Columbia University.*—Eleven weak field Zeeman components of the $F=9/2 \leftrightarrow F=11/2$ line of the metastable $(4p)^5(5s)\ ^3P_2$ state of $_{36}Kr^{83}$, $I=9/2$, have been observed by the atomic beam magnetic resonance method. The metastable state is populated in a beam by electron bombardment and detected by Auger ejection of electrons from a cesium surface. The preliminary result of 1342 Mc/sec for the zero field splitting agrees with the optical measurements of Bayer-Helms.[1]

* Work supported in part by a joint service contract with the U. S. Army Signal Corps, the Office of Naval Research, and the U. S. Air Force Office of Scientific Research and in part by a contract with the U. S. Air Force monitored by the U. S. Air Force Office of Scientific Research.
[1] Bayer-Helms, Z. Physik 154, 175 (1959).

Y5. Precise Measurement of Level Crossing Fields for $Cd^{111,113}$.* P. THADDEUS AND R. NOVICK, *Columbia University.*—The crossing point[1] of the $(\frac{1}{2},-\frac{1}{2})$ and $(\frac{3}{2},\frac{3}{2})$ hyperfine levels of the $5s5p^3P_1$ state has been determined to lie at 1964.48 ± 0.07 gauss for Cd^{111} and 2054.99 ± 0.07 gauss for Cd^{113}. A line width for the crossing of 0.17 gauss, about three times that expected from the known lifetime of the $5s5p^3P_1$ state, has been obtained by improving the magnetic field homogeneity. By using field modulation and phase sensitive detection at 30 cps, a signal-to-noise ratio of about 50:1 has been attained with a detector time constant of 10 sec.

* Work supported in part by a joint service contract with the U. S. Army Signal Corps, the Office of Naval Research, and the U. S. Air Force Office of Scientific Research and in part by a contract with the U. S. Air Force monitored by the U. S. Air Force Office of Scientific Research.
[1] M. N. McDermott, R. Novick, and P. Thaddeus, Bull. Am. Phys. Soc. Ser. II, 5, 411 (1960).

Y6. Hyperfine Frequency Shifts Produced by Resonance Radiation Light Intensity. M. A. ARDITI, *ITT Laboratories,* AND T. R. CARVER, *Princeton University.*—Measurements have been made by previously reported optical transmission techniques of the $m_F=0$ hyperfine transitions in Rb^{87} and Cs^{133} which indicate the presence of a positive frequency shift proportional to light intensity which may be as large as 200 cycles in the case of Cs and 70 cycles in the case of Rb. Such a shift is reasonably to be expected where the two levels are coupled by resonance radiation in which a fraction of the absorption and re-emission is coherent. Pressure shifts, due to the Doppler reducing buffer gas, and temperature coefficients of the pressure shift have been reported previously, but it appears that because of the variation of transmitted light with temperature and consequent change in vapor pressure of the alkali metal, the temperature shift must be re-examined. In support of the contention that coherency in light absorption and emission is responsible, it has been found that the use of very high buffer gas pressures, which are known to mix the hyperfine states of the excited state, will cause the optical intensity shift to disappear. This shift appears to explain discrepancies in the case of Cs^{133} between measurements of the hyperfine splitting made by optical detection and by atomic beam methods.

Y7. Hyperfine Structure of Tm^{166}.* J. C. WALKER AND D. L. HARRIS, *Princeton University.*—The nuclear spin and hyperfine structure of Tm^{166} (7.7 hr) have been measured by the atomic beam magnetic resonance method with radioactive detection. A self-normalizing "flop-in" geometry was utilized in the beam detection. The isotope was produced both by $Er^{166}(p,n)Tm^{166}$ and $Ho^{165}(\alpha-3n)Tm^{166}$ reactions. Three one-quantum transitions have been observed at several magnetic fields, and multiple quantum transitions also have been observed in some cases. From the quadratic shifts observed in the resonances corresponding to these transitions we obtain the following very approximate results: $|a|=100\pm50$Mc/sec, $|b|=24\,000\pm2000$ Mc/sec, with $b/a>0$. We have experienced considerable difficulty with these measurements due to an anomalous narrowing and a severe power pulling of the resonances. Work is being done to correct this and to improve the accuracy of our measurement of the zero-field hfs intervals. It should be noted that the above value of $|b|$ leads to a value of $|Q|>10$ barns and results in a rather unusual zero-field hyperfine level ordering.

* This work was supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.

Y8. Hyperfine Structure of a Forbidden Line in the Spectrum of Pb II.* C. DANIEL COLE, *Bell Aerosystems Company.*—On continuing the study of forbidden lines previously reported,[1] a forbidden line of mixed character (magnetic dipole and electric quadrupole) was found at 7099.8 A in the spectrum of Pb II. It corresponds to the transition $^2P_{\frac{1}{2}}^0 \rightarrow {}^2P_{\frac{3}{2}}^0$. Both of these levels belong to the electron configuration $6s^26p$. A line having the same wavelength was recorded by Walters in 1922[2] but positive identification was not made. In the present study, the hyperfine structure was photographed, and the results of measurements of the component positions were compared with values obtained theoretically. As with other atoms and ions homologous with Pb II, the agreement is not good because of a perturbation of the $^2P_{\frac{1}{2}}^0$ level by some other level. However, when the positions are calculated by correcting corresponding results observed for the same levels of Tl I for differences in the lead and thallium nuclei, the agreement is satisfactory.

* This research was performed at the Department of Physics, University of Buffalo, Buffalo, New York.
[1] C. Daniel Cole, Bull. Am. Phys. Soc. Sec. II, 5, 412 (1960).
[2] F. M. Walters, Jr., Sci. Papers Bur. Standards 17, 161 (1922).

Y9. Magnetic Dipole and Electric Quadrupole Interaction Constants of Bi^{210}.* S. S. ALPERT, E. LIPWORTH, M. B. WHITE, AND K. F. SMITH,† *Lawrence Radiation Laboratory, Berkeley.*—

The magnetic dipole interaction constant a and the electric quadrupole interaction constant b were measured for Bi^{210} ($I=1$, $T_{\frac{1}{2}}=5.0$ days) using the method of atomic beams. These results were $a=21.78\pm0.03$ Mc/sec and $b=112.38\pm0.03$ Mc/sec. Sixteen "flop-in" resonances were observed including the three direct transitions ($F=\frac{3}{2}$, $m=\frac{1}{2} \leftrightarrow F=\frac{3}{2}$, $m=\frac{1}{2}$), ($F=\frac{3}{2}$, $m=\frac{1}{2} \leftrightarrow F=\frac{1}{2}$, $m=-\frac{1}{2}$), and ($F=\frac{3}{2}$, $m=-\frac{1}{2} \leftrightarrow F=\frac{1}{2}$, $m=\frac{1}{2}$). The radioactive isotope was produced from the stable metal by the reaction $Bi^{209}(n,\gamma)Bi^{210}$ in the Livermore Pool Type Reactor. Detection was accomplished by collection on sulfur-coated "buttons" which were counted in continuous flow beta counters.

* Supported by the U. S. Atomic Energy Commission and the U. S. Air Force Office of Scientific Research.
† On leave from the Cavendish Laboratory, Cambridge, England.

Y10. Lifetime of the $^2S_{\frac{1}{2}}$ State of Thallium by Optical Double Resonance. EDWIN L. TOLANS AND ALLEN LURIO, *IBM Watson Laboratory*.—The $\Delta F=0$, $\Delta m_F=\pm1$ transitions in the $F=1$ hyperfine level of the $^2S_{\frac{1}{2}}$ state of thallium ($I=\frac{1}{2}$) have been observed by the optical double resonance technique. A beam of thallium atoms produced from an oven with a directional, crinkle foil source was excited by circularly polarized resonance radiation of 3776 A ($^2P_{\frac{1}{2}}-^2S_{\frac{1}{2}}$) from an external thallium lamp. These Zeeman transitions were induced by a 60-Mc/sec rf field. The resonance was observed by monitoring the change in polarization of the fluorescence re-radiation at 5350 A ($^2S_{\frac{1}{2}}-^2P_{\frac{1}{2}}$) as the applied dc magnetic field was swept through the resonance. This dc field was applied in the direction of the incident 3776 A radiation and the photoelectrically observed re-radiation. A preliminary value for the lifetime of the $^2S_{\frac{1}{2}}$ state was obtained by extrapolation of the width of the Zeeman resonance to zero rf field. The value is $8.9\pm1.0\times10^{-9}$ sec. The experiment is being repeated at 95 Mc/sec to reduce possible distortions of the resonance line shape arising when the rf and dc magnetic fields are comparable. A measurement of the zero field hyperfine structure separation in the $^2S_{\frac{1}{2}}$ state is being planned.

Y11. Study by the Mössbauer Method of the hfs Splitting of Au^{197} Alloyed in Fe. L. D. ROBERTS, *Oak Ridge National Laboratory*, AND J. O. THOMSON, *University of Tennessee*.—Au^{197} has a $\frac{3}{2}+$ ground state and a $\frac{1}{2}+$ first excited state at 77 kev. Although gold is normally nonmagnetic, when it is alloyed in iron it partakes of the ferromagnetism of the latter through a magnetic polarization process.[1] This produces a hfs splitting of the above two gold levels which we have studied for a one atomic percent gold in iron alloy. The measurements were made at helium temperatures by the Mössbauer method using a Pt^{197} in platinum metal source and the above Au-Fe alloy as absorber. In a preliminary experiment we observed two lines, each being an unresolved triplet. The separation of these lines is approximately 1.1 cm/sec with a line width of about 0.6 cm/sec. A quite large chemical shift of about 0.5 cm/sec was found. For the excited state these measurements give $|\mu_n H_0|=4.5\times10^6$.

[1] B. N. Samoilov, V. V. Sklyarevsky, and E. P. Stepanov, *International Conference on Low Temperature Physics, Toronto* (September, 1960), p. 415.

Y12. Nuclear Polarization.* WILLIAM A. BARKER, *St. Louis University*.—The population distribution and nuclear polarization achieved by static or dynamic methods depends on several factors: (1) The magnitude of the nuclear Zeeman energy as compared to the hyperfine interaction energy. (2) The algebraic sign of the nuclear magnetic moment. (3) The algebraic sign of the hyperfine interaction constant. (4) The magnitude and orientation of the "Pumping" radiation. (5) The type and relative magnitude of the relaxation mechanisms. Four static and twenty-four dynamic cases will be discussed.

* This work has been supported in part by the U. S. Atomic Energy Commission and in part by the U. S. Air Force Office of Scientific Research.

SATURDAY AFTERNOON AT 1:30

Statler-Hilton, Skytop Room

(R. W. MORSE presiding)

Mechanical and Thermal Properties of Solids

YA1. Order Dependent Specific Heat of Cu_3Au.* FRANK J. LOSACCO AND LEON J. SCHKOLNICK, *Columbia University*.—The variation of the order dependent specific heat of Cu_3Au with temperature through the order-disorder transformation has been measured. The results will be discussed in connection with the known kinetics of the disordering process, as will also their role in the determination of the latent heat of the order-disorder transformation. Novel features of the experimental method, which is applicable to specimens of mass approximately 10 g, will be described.

* This research was supported by the Esso Education Foundation Fellowship, the Union Carbide Nuclear Company Fellowship in Physics, and the U. S. Army Office of Ordnance Research.

YA2. Order Dependent Thermal and Electrical Conductivity of Cu_3Au.* SAMUEL D. LINDENBAUM, *Columbia University*.—Measurements of the temperature variations of the thermal and electrical conductivities of Cu_3Au between 100°C and 420°C have been made upon the same specimen following the same prior heat treatment. The problem of deducing the order dependent contributions to these properties will be discussed. The method for measuring the thermal conductivity, which is applicable to specimens in the form of rods a few mm in diameter and a few cm long, is novel and will be described.

* This research was supported by the U. S. Army Office of Ordnance Research.

YA3. Some Experiments in Friction and Adhesion with the Face-Centered Cubic Metals. M. E. SIKORSKI, J. R. APEN, AND N. A. STRAKHOV, *Bell Telephone Laboratories*.—A torquemeter has been added to the apparatus used for the determination of coefficients of adhesion of metals in air.[1-3] It is now possible to determine the coefficients of friction at different stages of the build-up of adhesive bonds. Very high values of the coefficients of friction and adhesion were obtained for Ag, Al, Au, Cu, Ni, Pb, Pd, and Pt. These values are of the same order of magnitude as those obtained by F. P. Bowden and G. W. Rowe.[4] There was an important difference in the experimental conditions, however; while our data were obtained in air, Bowden and Rowe's samples were outgassed in a vacuum of the order of 10^{-5} μ. Effects of surface preparation and degreasing on samples of copper are discussed.

[1] P. Andreatch and O. L. Anderson, Rev. Sci. Instr. **30**, 498 (1959).
[2] O. L. Anderson, J. Appl. Phys. **30**, 593 (1959).
[3] O. L. Anderson, Wear **3**, 253 (1960).
[4] F. P. Bowden and G. W. Rowe, Proc. Roy. Soc. (London) **A233**, 429 (1956).

YA4. Elastic Constants of Single Crystal Mo and W. J. DE KLERK AND D. I. BOLEF, *Westinghouse Research Laboratories.*—The adiabatic elastic constants of single crystals of molybdenum and tungsten have been measured between −196°C and +200°C. The crystals, obtained commercially, were grown by an arc fusion technique. (100) and (110) faces were exposed, permitting five independent measurements of sound velocity. Measurements were made at 10 Mc using a high-frequency ultrasonic cw resonance technique. With this technique, the end corrections due to the transducer and bond could be calculated accurately. The elastic constants are, in units of 10^{12} dynes/cm^2,

	C_{11}	C_{44}	$1/2(C_{11}-C_{12})$	ρ (g/cc)
Mo $T=298°K$	4.70	1.099	1.58	10.220
$T=77°K$	4.80	1.118	1.64	10.248
W $T=298°K$	5.22	1.604	1.58	19.265
$T=77°K$	5.31	1.626	1.62	19.316

Attenuation measurements as a function of temperature were made using the ultrasonic pulse-echo technique.

YA5. Anomalies in the Elastic Constants and Ultrasonic Attenuation in Cr. D. I. BOLEF, J. DE KLERK, AND R. W. GUERNSEY, *Westinghouse Research Laboratories.*—An investigation of the temperature dependence of the elastic constants of single crystal Cr has revealed a striking anomaly at 37°C and a less marked anomaly at −152°C for both longitudinal and transverse sound waves. At both temperatures there is an abrupt reversal of sign of the temperature coefficients of the elastic constants and a corresponding increase in acoustic attenuation. The temperature range investigated was −195°C to +100°C. The elastic constants were measured at 10 Mc by means of an ultrasonic cw resonance technique. The attenuation was measured by an ultrasonic pulse-echo technique. The single crystals, kindly supplied by Dr. John Marcinkowski, had (100) and (110) faces exposed, permitting five independent measurements of sound velocity.

YA6. Elastic Constants of Iron from 4.2–300°K. B. S. CHANDRASEKHAR AND J. A. RAYNE, *Westinghouse Research Laboratories.*—The zero field elastic constants of iron have been measured from 4.2–300°K using the ultrasonic pulse technique. Extrapolation of the data to absolute zero gives $C_{11}=2.431\pm0.008$, $C_{12}=1.381\pm0.004$, and $C_{44}=1.219\pm0.004$, all expressed in units of 10^{12} dyne cm^{-2}. The corresponding limiting value of the Debye temperature is $\theta_0=477\pm2$°K. By using this figure, the low-temperature heat capacity data[1] for iron have been reanalyzed, assuming the presence of a spin-wave contribution to the specific heat, i.e., the heat capacity is assumed to follow the relation $C=\gamma T+\beta T^3+\alpha T^{\frac{1}{2}}$. A least-squares fit of $(C-\beta T^3)/T$ vs $T^{\frac{1}{2}}$ gives $\gamma=11.7\pm0.1\times10^{-4}$ cal mole^{-1} deg^{-2}, $\alpha=2\pm1\times10^{-4}$ cal mole^{-1} deg$^{-5/2}$. There is agreement, within experimental error, between the latter figure and the theoretical estimate of $\alpha=0.8\times10^{-4}$ cal mole^{-1} deg$^{-5/2}$, obtained from the low-temperature magnetization data of Fallot.[2] From the room-temperature elastic constants, the compressibility of iron is found to be $\beta=5.95\pm0.02\times10^{-13}$ cm^2 dyne^{-1}, which agrees exactly with the static value obtained by Bridgman.[3]

[1] C. H. Cheng, C. T. Wei, and P. A. Beck, Phys. Rev. (to be published).
[2] M. Fallot, Ann. phys. 6, 305 (1936).
[3] P. W. Bridgman, Proc. Am. Acad. Arts Sci. 77, 187 (1949).

YA7. Effect of Interstitial Li on the Density of Si.* J. S. PRENER, E. M. PELL, AND F. E. WILLIAMS, *General Electric Research Laboratory.*—Densities of Merck vacuum grown floating zone Si and of Si containing 10^{19} Li/cm^3 in solution were determined using a density gradient column. The density was also measured during the room-temperature aggregation of Li which was monitored by resistivity measurements. At 27.4°C, the measured density of pure Si was 2.32906 g/cm^3, in rather close agreement with Smakula.[1] When Li dissolves in Si, there is a volume increase of 4.7×10^{-24} cm^3/Li. This is interpreted as due to electrostatic repulsion between Li^+ and the partly shielded Si^{+4} cores. A simple model involving Si^{+4} cores and spherically symmetric bonding electrons centered between the cores yields a potential at the Li^+ consistent with an effective charge on the Si of approximately +0.1 calculated from the expansion. During the initial conversion of Li^+ to aggregated Li^0, the volume increases by 6.0×10^{-24} cm^3/Li. This is interpreted as due to overlap repulsion between interstitial Li^0 and Si. The coincidence of deionization and aggregation appears plausible from the properties of Li_2 and Li metal. A subsequent nonlinear expansion may involve formation of a separate phase.

* Partially supported by U. S. Air Force Cambridge Research Center.
[1] A. Smakula, J. Kalnajs, and V. Sils, Phys. Rev. 99, 1747 (1955).

YA8. Deformation of Dislocation-Free Crystals of Zinc and Cadmium. P. BUFORD PRICE, *General Electric Research Laboratory.*—Electron-transparent, vapor-grown crystals of zinc and cadmium with their largest faces in the basal plane was deformed in tension inside the electron microscope at temperatures ranging from 20°C to −100°C and the processes of deformation directly observed by the transmission technique. All of the crystals were initially free of dislocations. Since the axis of tension was parallel to the (0001) plane, basal slip could not occur. Instead, plastic deformation proceeded in one of three ways: (1) A narrow, wedge-shaped twin was nucleated at one edge of the crystal, grew in length until it extended across the crystal, and then began to grow in width; (2) dislocations with predominantly screw orientation and a Burgers vector $\frac{1}{3}[11\bar{2}3]=c+a$ were produced, giving rise to pyramidal slip on the $(\bar{1}122)[11\bar{2}3]$ system; (3) dislocations with predominantly edge orientation and a Burgers vector $\frac{1}{3}[11\bar{2}0]=a$ were produced and caused slip on nonbasal planes. The third process was only observed in cadmium. This and other differences in the deformation of zinc and cadmium will be discussed, and the behavior of these nearly perfect crystals will be compared with that of ordinary large crystals of zinc and cadmium having the same orientation.

YA9. Lattice Parameters and Structural Changes in the Pseudo-Binary Alloy GeTe-SnTe.* J. N. BIERLY, *The Franklin Institute Laboratories,* L. MULDAWER, *Temple University,* AND O. BECKMAN, *University of Uppsala, Uppsala, Sweden.*—Measurements of the room temperature lattice constants of the pseudo-binary alloy GeTe-SnTe show a continuous transformation from a face-centered rhombohedral structure at GeTe to a NaCl type structure starting at 30% GeTe–70% SnTe and continuing to SnTe. Determinations of the structure above and below room temperature reveal a continuous variation in structure as a function of composition and temperature. GeTe is rhombohedral at room temperature and generally transforms to a NaCl type structure, $T_c=390$°C. As the percentage of SnTe is increased in the alloy system, the temperature at which the rhombohedral structure transforms to a NaCl structure is decreased, and beyond 70% SnTe the transformation occurs below room temperature. SnTe retains a NaCl structure at least to 77°C. Metallographic examination of the alloys reveals a banded structure in alloys which were rhombohedral at room temperature. These are interpreted as being twin bands and are thought to arise from the strain at the cubic-rhombohedral interface.

* Work sponsored by the Thermoelectric Effects Research Program.

YA10. Normal Processes in Thermal Conductivity. JOSEPH CALLAWAY, *University of California, Riverside.*—Since normal three phonon scattering processes conserve the total wave

vector of the phonon system, addition of reciprocal relaxation times for all phonon scattering mechanisms is not valid when normal processes are dominant. A formula previously proposed for the computation of lattice thermal conductivities[1] is analyzed in the limit of strong normal processes. In this limit the thermal resistivity is the sum of contributions from defect scattering, boundary scattering, and residual Umklapp scattering. If the relaxation time for defect scattering is $\tau_D^{-1}=A\omega^4$, then the resistivity due to point defects is, in this limit, $W_D=120\pi^3VAT/h$, where V is the velocity of sound, in agreement with the theory of Ziman.[2] If defect scattering is not weak, addition of thermal resistivities is not valid, and the Ziman formula is an overestimate. The thermal conductivity will be exhibited as a function of the ratio of the relaxation times of point defect to normal three phonon scatterings.

[1] J. Callaway, Phys. Rev. **113**, 1046 (1959).
[2] J. M. Ziman, Can. J. Phys. **34**, 1256 (1956).

YA11. Residual Thermoelastic Stresses in Bonded Silicon Wafers. T. D. RINEY,* *Bell Telephone Laboratories* (introduced by J. H. McGinn).—The residual thermoelastic stresses produced in a silicon strip when eutectic-bonded to a gold-plated molybdenum block are investigated photoelastically using near infrared light and an image converter tube. This is the two-dimensional analog of a problem arising when silicon wafers are bonded to headers in semiconductor devices. It is first shown that with the proper orientation of the crystal the specimen may be studied by the methods normally employed with isotropic birefringent materials. This simplifies the quantitative evaluation of the stresses. It is found that, though the mean longitudinal stress near the center of the strip is compressive, a transverse tensile stress of greater magnitude occurs near the ends of the strip. This "tearing stress" is determined to be approximately 1.1×10^9 dynes/cm^2 at room temperature.

* Now with Space Sciences Laboratory, General Electric Company, Philadelphia, Pennsylvania.

SATURDAY AFTERNOON AT 1:30

New Yorker, Panel Room

(N. M. KROLL presiding)

Theoretical Physics VIII: Nuclear Structure

Z1. Rotational Model for Fe^{57}.* R. D. LAWSON AND M. H. MACFARLANE, *Argonne National Laboratory*.—An attempt has been made to describe the low-lying levels of Fe^{57} in terms of a single particle moving in the deformed field of an axially symmetric rotor. The full rotational Hamiltonian, including Coriolis coupling, has been used. The predictions of the model are insensitive to sizable variations in the moment of inertia and in the parameters of the Nilsson potential. At a deformation η between 2 and 3, satisfactory agreement is obtained with the observed level structure below 1 Mev. This value of η is consistent with $B(E2)$ for Coulomb excitation of the second excited state and with the magnetic moment and the negative sign of the quadrupole moment of the first excited state. The predicted ground-state magnetic moment disagrees with experiment, $M1$ matrix elements are consistently overestimated by a factor of 2, and the $^2p_{\frac{1}{2}}$ contribution to the ground-state wave function is far too small to account for the reduced width of the $Fe^{57}(d,t)Fe^{56}$ ground state.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

Z2. A Cranked-Model Theorem.* MURRAY PESHKIN, *Argonne National Laboratory*.—It is proved that Inglis's[1] cranked-model formula for nuclear moments of inertia necessarily gives *at least* the "irrotational" value,

$$M\frac{(\langle x^2\rangle_{\rm av}-\langle y^2\rangle_{\rm av})^2}{\langle x^2\rangle_{\rm av}+\langle y^2\rangle_{\rm av}},$$

under the following assumptions: (1) The Hamiltonian consists of the usual kinetic energy plus a slowly rotating potential energy. (2) The potential energy is an arbitrary function of positions alone, except that it may not be invariant under rotation. In particular, it may contain collective and/or interparticle interactions. It may, but need not, be invariant under translation.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

Z3. Rotational Levels Resulting from Single-Particle Excitation. DANIEL SPERBER,* *Armour Research Foundation*.—Rotational levels in nuclei having many nucleons outside of closed shells have been discussed. Also the distribution in energy and angular momentum of more highly excited levels has been studied by Bloch and Ericson. Here the question of the lowest eigenvalue corresponding to any given high angular momentum has been investigated for nuclei which have no nucleons outside of closed shells when in the ground state. We assumed that the energy is the sum of the single particle energies predicted by the shell model. A variational calculation was performed to minimize the energy for a specified number of nucleons and angular momentum. We obtained for the rotational energy

$$E_r=\frac{6\hbar\omega I(I+1)}{(l_{f+}+1)(2l_{f+}{}^3+10l_{f+}{}^2+15l_{f+}+6)+(l_{f-}(l_{f-}+1)(2l_{f-}{}^2+2l_{f-}-1)}.$$

Here ω is the oscillator frequency, I is the specified angular momentum, and l_{f+} and l_{f-} are the highest single-particle momenta of the last closed shells for which $j=l+\frac{1}{2}$ and $j=l-\frac{1}{2}$, respectively. The moment of inertia depends on the spin orbit interaction indirectly.

* Work performed at Princeton University.

Z4. Calculations on Energy Spectra in Lithium Isotopes.* L. D. PEARLSTEIN,† Y. C. TANG, AND K. WILDERMUTH, *Florida State University*.—The energies of the first six levels of Li^6 and four levels of Li^7 are calculated with a variational method. The trial wave functions are so chosen as to exhibit the feature of relatively long-range correlations as clustering of nucleons in those nuclei. To simplify computations, we adopt the L-S coupling scheme and assume the wave functions describing excited clusters need not be considered. These assumptions are expected to be approximately valid, since we are only interested in energy levels with low excitation energies. The interaction energy between the clusters is calculated with a Serber force which describes low-energy nucleon-nucleon scattering data. Short-range correlations resulting from the repulsive core have been taken into account only in a very rough manner. Numerical results indicate that our computa-

tions yield fair agreement with the experimentally observed spectra for both Li^7 and Li^6. Possible ways to improve our results will be presented. Limitations of our method of calculations will also be discussed.

* Supported in part by the Office of Naval Research.
† Now at General Atomic, San Diego, California.

Z5. Phase Shift Analysis of α-α Scattering.* E. W. SCHMID AND K. WILDERMUTH, *Florida State University* and *Oak Ridge National Laboratory*.—The integral-differential equation for the alpha-alpha-scattering was derived using two-body Serber forces which describe the low energy nucleon-nucleon scattering data up to around 50 Mev. To simplify calculations, assumptions have been made that, during the scattering process, the alpha clusters are not excited and their radii remain unchanged. This approximation is expected to be valid, since it is in agreement with the shell model picture of Be^8.[1] Furthermore, it is well known that the alpha particle needs about 20 Mev to be excited and has a rather small compressibility. Numerical integrations were carried out on an IBM 704 electronic computer. The $L=0$, 2, 4 phase shifts thus obtained show good agreement with the experimental results.[2]

* Supported in part by contract with the Office of Naval Research.
[1] K. Wildermuth and Th. Kanellopoulos, Nuclear Phys. 9, 449 (1959); L. D. Pearlstein, Y. C. Tang, and K. Wildermuth, Nuclear Phys. 18, 23 (1960).
[2] N. P. Heydenburg and G. M. Temmer, Phys. Rev. 104, 123 (1956); J. L. Russell, Jr., G. C. Phillips, and C. W. Reich, *ibid.* 104, 135 (1956); R. Nilson, W. K. Jentschke, G. R. Briggs, R. O. Kennan, and J. N. Snyder, *ibid.* 109, 850 (1958).

Z6. Effect of Cluster Structure on the Coulomb Energy Difference of Mirror Levels.* K. WILDERMUTH AND Y. C. TANG, *Florida State University*.—The assertion of the cluster model that different energy levels of the same nucleus can have entirely different cluster structures has been verified by recent analyses on the energy spectra of light and medium weight nuclei.[1] As the charge distribution of a nucleus is closely related to the wave function which describes the state in question, one would expect that the cluster structure may influence the Coulomb energy to a considerable extent. Thus by studying the excitation energy difference of corresponding levels in a mirror pair, one can hope to gain some information about the structure of those levels. An example of this kind is the $(\frac{1}{2}-)$ levels in F^{17} and O^{17}. A careful examination of the Coulomb energy behavior of these levels would indicate a structure composed of an excited O^{16}-core and a proton or neutron in relative oscillation. This assumed structure is indeed consistent with that inferred from (d,p) stripping reaction on O^{16}.[2] Many other examples also exist in the region of light nuclei. In general, our predicted level structures agree very well with those inferred from experimental observations.

* Supported in part by the Office of Naval Research.
[1] R. K. Sheline and K. Wildermuth, Bull. Am. Phys. Soc. Ser. II, 4, 271 (1960).
[2] T. S. Green and R. Middleton, Proc. Roy. Soc. (London) A69, 28 (1956).

Z7. Surface Properties of Nuclear Matter.* JOHN C. REYNOLDS,† *Harvard University*.—The density and effective potential across a plane surface of nuclear matter have been calculated in the Hartree-Fock approximation. The depth and range of the interparticle potential are fitted to low-energy scattering data. Nuclear saturation is produced by using an admixture of exchange forces. The resulting binding energy per particle is 4.0 Mev, compared with a value of about 15 Mev given by the Weizsäcker semiempirical mass formula. The thickness of the resulting surface (the distance over which the density drops from 90% to 10% of its asymptotic value in the interior) is 2.0 fermis. The density function exhibits oscillations near the surface due to the sharpness of the edge. A similar computation is now in progress using an approximation which takes into account certain two-body correlation effects. This approximation has been used by R. D. Puff to study nuclear saturation in homogeneous matter. The approximation includes the effect of the repulsive hard core and gives good agreement with the Weizsäcker binding energy.

* Electronic calculations were performed at the M.I.T. Computation Center, Cambridge, Massachusetts, and the research supported in part by the U. S. Air Force Office of Scientific Research.
[1] National Science Foundation predoctoral fellow.

Z8. Odd-Even Shifting in the $K=0$ Band of Odd-Odd Deformed Nuclei.* NEAL D. NEWBY, JR., *Lawrence Radiation Laboratory, Berkeley*.—Experiment indicates that there is a relative shift in the energy levels of odd and even spin in the $K=0$ band of odd-odd strongly deformed nuclei. This displacement is superposed on the expected rotational level structure of the $K=0$ band. It has been suggested that such an effect may be understandable as the result of a residual two-body force between the two odd nucleons. This suggestion is explored in some detail. It is found that the experiments measure only a part of the diagonal matrix element. This part, however, because it involves scatterings from one state of strongly polarized intrinsic spin to another, is especially sensitive to the *type* of two-body interaction used. Certain selection rules are found. The Wigner component of the two-nucleon interaction cannot contribute to the odd-even shift, independent of nuclear deformation. Other selection rules, rigorously true in the asymptotic limit and approximately true for strongly deformed nuclei, will be given. The situation is particularly interesting in Am^{243} where the asymptotic selection rules forbid contributions to the odd-even shift from any *central* forces. Results of numerical calculations for Ho^{165}, Am^{243}, and Ta^{180} using Nilsson wave functions will be presented.

* This research was performed under the auspices of the U. S. Atomic Energy Commission.

Z9. Rotational Energies of Asymmetric Odd-A Nuclei.* K. T. HECHT, *University of Michigan*.—Rotational energies of asymmetric odd-A nuclei are shown to be eigenvalues of $(I+\frac{1}{2})\times(I+\frac{1}{2})$ matrices. The matrix elements are functions of the inertial parameters and the coefficients $C_{j\Omega}$ which give the intrinsic particle wave functions in terms of limiting spherical shell model functions, $\chi(\text{particle})=\Sigma C_{j\Omega}\chi_{j\Omega}$. Examples are given based on calculations of $C_{j\Omega}$ by Newton[1] and extensions thereof. Expressions for radiation transition probabilities and nucleon reduced widths are generalizations of formulas for the axially symmetric case, involving additional sums over the symmetric rotator quantum number K. Through a change from an $IKj\Omega$ to an $IjRK_R$ representation it is seen that the special case discussed by Davydov,[2] in which $j=\frac{1}{2}$ is assumed to be a good quantum number, has rotational energies identical with those for even-even nuclei with states of given rotational angular momentum quantum number R, doubly degenerate, with total angular momenta $I=R\pm\frac{1}{2}$.

* Supported in part by the Office of Naval Research.
[1] T. D. Newton, Chalk River Rept. CRT 886 (1960).
[2] A. S. Davydov, Soviet Phys.—JETP 9, 1103 (1959).

Z10. Pairing Effects and Nuclear Shapes.* MICHEL BARANGER, *Carnegie Institute of Technology*.—Starting from a shell-model Hamiltonian, we perform the generalized Bogoliubov transformation,[1] i.e., we let the two states that pair with each other be completely arbitrary. There results a generalization of the Hartree-Fock equations which contains two potentials, the Hartree potential and the "pairing potential," emphasizing what Bohr and Mottelson have called the two main effects of nuclear forces, the field-producing effect and the pairing effect. Some solutions are spherically symmetric, some are not, and the solution with lowest total energy is to be preferred. Near closed shells, the spherical solution is the stable one, but as the number of valence nucleons is increased a deformed solution eventually becomes the lowest. If the deformation can be

assumed small, one finds that this transition occurs precisely at the point where collective vibrations of the spherical nucleus, as calculated by the method of linearized equations of motion,[2] cease to exist. However, deformations of actual nuclei are not small, hence nonlinear effects are important in the spherical region.

* Supported by the Office of Naval Research.
[1] N. Bogoliubov, Soviet Phys.—Uspekhi 2, 236 (1960).
[2] M. Baranger, Phys. Rev. 120, 957 (1960).

Z11. Theory of the Photonuclear Giant Resonance.* THOMAS ERBER, *Illinois Institute of Technology.*—Several features of the photonuclear giant resonance may be simply understood in terms of the excitation of a "strongly coupled" electrodynamic collective mode. This type of mode is intermediate between free field oscillations and the plasma modes. It depends nonanalytically on the coupling constant e^2 and cannot be reached through conventional perturbation theory. Classically this mode corresponds to the force-free vibrations of Herglotz and Sommerfeld; quantum mechanically it is the "exceptional" mode of Van Kampen's dipole Hamiltonian. Surprisingly high energies can be stored in such a mode. If we replace the phenomenological hydrodynamics of Steinwedel and Jensen by the appropriate electrodynamic eigenvalue problem, we find that E_m, the energy peak of the giant resonance, is given by $E_m=\eta 196(Z/A)/(r_0A^{\frac{1}{3}})$. η is a slowly varying function ~ 1; r_0 is taken from Hofstadter's data on nuclear radii. There is excellent agreement with the $(\gamma,\bar{\gamma})$ data of Fuller and Hayward. For $A>50$ there is also good agreement with the (γ,p) and (γ,n) results. Even the pause in E_m at $A\sim 59$ is reproduced. In contrast to the line narrowing predicted by the plasma picture, the present theory explains the progressive washing out of the resonance at low A directly in terms of Hofstadter's charge density profiles. The purely electromagnetic character of this mode presumably accounts for the preferential de-excitation by proton emission.

* Supported by the National Science Foundation.

Z12. Center-of-Mass Invariance and the Energy Shift in the Nuclear Dipole State.* STAVROS FALLIEROS, *Bartol Research Foundation.*—An estimate of the effect of the particle-hole interactions in shifting the energy of the nuclear dipole state has been obtained. Use has been made of the requirement of translational invariance, which implies certain relations between the space-dependent parts of the particle-hole and particle-shell interaction matrix elements. Within the conventional shell-model framework, it is found that the direct and exchange integrals in the particle-hole interaction are respectively equal to the corresponding integrals appearing in the particle-shell term. If the rather small contribution due to odd-state forces is neglected, an approximate value of one-half is obtained for the ratio of the total energy shift to the potential-energy part of the average single-particle excitation energy. The upward shift in the energy of the dipole state is found to be mainly due to the effect of the triplet-even nucleon-nucleon forces. In the $S=0$ component of this state, the singlet-even forces have an attractive contribution which tends to lower the total excitation energy.

* Supported by the Office of Naval Research.

Z13. Ca^{40} Giant-Dipole Resonance.* Y. C. LEE, *University of Maryland.*—A shell-model calculation of the type already carried out by Elliott and Flowers for O^{16} has been completed for Ca^{40}, for finite-range nuclear forces. Thus we are able to test the sensitivity of the zero-range calculations of Brown and co-workers to the range of the force. An additional feature of interest is the effect of the spin-orbit splitting in splitting the giant dipole resonance into two levels.[1] The highest energy triplet and highest energy singlet states are mixed by the spin-orbit interaction. The calculation also has been carried out in the extended shell model, including the backward-going graphs and thereby allowing for correlation in the ground state.[2] A difficulty in the comparison of the results of the calculation with experiment is the lack of experimental data on the energy and spin-orbit splitting of a single hole in the Ca^{40} doubly filled shell.

* Investigation supported in part by the Office of Naval Research and in part by the U. S. Atomic Energy Commission.
[1] M. K. Pal and Y. C. Lee, Bull. Am. Phys. Soc. Sec. II, 4, 406 (1959).
[2] R. A. Ferrell, Bull. Am. Phys. Soc. Ser. II, 4, 59 (1959).

Z14. Configuration Interaction in the Nuclear Optical Model. M. DANOS.* *University of Heidelberg and National Bureau of Standards.*—Configurations of the same symmetry which have similar energy in first approximation in the shell model in general tend to interact. This results in energy shifts of the states, the magnitudes of which are given by the interaction energies. For the continuum states an incoming particle must remain in the nucleus long enough to be able to excite the other configurations before it leaves the nucleus again. Therefore, S neutrons will experience very little configuration interaction, and the usual optical model description is adequate. With increasing angular momentum, the ratio of particle width to interaction energy will decrease because the increase in the centrifugal barrier and the excitation of other configurations will become more important. Under these conditions, besides the energy shift there also will occur a narrowing of the neutron giant resonance since only the original state corresponds to a neutron scattering on a nucleus in its ground state. The admixed configurations correspond to excited target nucleus states, and they cannot decay into the ground state by particle emission. Experimentally these effects will show up as fluctuations in the potential well parameters.

* Guggenheim Fellow 1959–1960.

SATUDAY AFTERNOON AT 1:30

New Yorker, Boston-Washington Room

(F. J. DYSON presiding)

Theoretical Physics IX; Field Theory II, Dispersion Relations

ZA1. Is Planck's h Gravitational in Origin? B. A. SOLDANO, *Oak Ridge National Laboratory.*—A gravitation model, based in part upon employing an expanding universe as a reference, is examined. This approach not only suggests that Planck's constant h is complex in structure, but that h contains factors which reflect the thermodynamic assumptions which originally led to Planck's solution of the blackbody problem. The model suggests a simple mathematical basis for the fundamental, albeit empirical, Schrödinger operator substitution. In addition, the fundamental constants and experimental yardsticks of physics, i.e., G, h, e, Rydberg's wavelength, etc., are shown to reflect a specific cozonal behavior of the exponential type.

Elements of this model, when combined with an absolute field and the terrestrial relativistic Schwartzchild ($2L$), agree, in the limit, with the Maxwell-Einstein weak-field approximation [$2G/c^4$], the quantitative indicator of the gravitational-electromagnetic massless field interaction. The model leads to a calculation of not only the "universal" Fermi-Gamow "weak interactions" coupling constant, but the high-energy nuclear coupling constant [$g^2/\hbar c$] as well.

ZA2. Phase Treatment of Field Oscillators.* J. WEBER, *University of Maryland.*—Phase is treated as a dynamical variable in quantum mechanics. To discuss the phase measurement problem in electrodynamics it is sufficient to treat the harmonic oscillator. A canonical transformation reduces the Hamiltonian to an especially simple form linear in the momentum conjugate to the phase. The trigonometric functions become the energy eigenfunctions, a complete set spanning half of the Hilbert space. Representations of the phase and functions of the phase are given.

* Supported by the Office of Naval Research.

ZA3. Time-Translation Invariance of Poisson Brackets in General Relativity.* JOHN G. FLETCHER,† *University of California, Berkeley.*—This paper relates to work[1] previously done by the author in which Poisson brackets between field variables in general relativity were obtained on an initial, time constant, surface. It is now shown that assuming the brackets to have the same form on all time constant surfaces is compatible with the equations of motion. From this it immediately follows that this same form is maintained on all space-like surfaces.

* This work supported in part by the Grumman Aircraft Engineering Corporation.
† Fellow of the Miller Institute for Basic Research in Science.
[1] J. G. Fletcher, Ann. Phys. (to be published).

ZA4. Possible Union of Space-Time and Isospace in ϵ_n. DAVID W. JOSEPH, *Purdue University.*—It recently has been proposed by Fronsdal[1] that quantum mechanics be reconciled with the curvature of space-time (and the theory of general relativity) through the introduction of a pseudo-Euclidean space ϵ_n, where general relativity indicates that $6 \leq n \leq 10$. On the one hand, such an approach has (in addition to conceptual advantages in the visualization of the space-time manifold) the advantage of a logical simplicity in the initial formulation of quantum mechanics,[2] as compared with the standard generally covariant formulations. On the other hand, it offers a rather natural interpretation of "isospace" as that subspace which is locally normal to the four-dimensional space-time manifold. This latter point will be considered in connection with a simple "classification" of baryons and bosons for the case $n = 11$.

[1] C. Fronsdal, Nuovo cimento **13**, 988 (1959).
[2] D. W. Joseph (to be submitted to Nuovo Cimento).

ZA5. Relativistic Electron-Pair Model of the π^0-Meson. E. J. STERNGLASS, *Westinghouse Research Laboratories.*—For the special case of equal mass particles in a steady-state circular orbit of angular momentum $L_i = \hbar$, the relativistic two-body problem can be solved for $v \simeq c$ if one assumes that the usual laws of electrodynamics and quantum mechanics continue to hold for distances as small as 10^{-14} cm. It is found that a minimum approach distance r_{min} occurs for any two-particle system in equilibrium under the action of electromagnetic and inertial forces where $\gamma = (1 - v^2/c^2)^{-\frac{1}{2}}$ tends to infinity. For two particles of equal rest-mass m_0 and opposite charge e, the distance $r_{min} = (1/4)(e^2/m_0c^2) = 0.70 \times 10^{-13}$ cm, independent of any assumptions as to the size of the charge distribution. The relativistic precession accounts for one-half of the total angular momentum for large γ values so that the orbital momentum relative to the precessing frame becomes $(\hbar/2)$ when $L_i = \hbar$. The total energy of this system is found to be $(2/\alpha)m_0c^2$, where $\alpha = e^2/\hbar c = (137.04)^{-1}$. Taking account of the intrinsic magnetic moment interaction corrected for the large relativistic effects, with spins oriented to give a total angular momentum zero, leads to a mass value of $266m_0$, in reasonable agreement with the observed π^0-mass.

ZA6. Application of the Mandelstam Representation to Photoproduction of Pions. JAMES S. BALL, *University of California, La Jolla.*—The Mandelstam representation is applied to the problem of photoproduction of pions from nucleons. By treating gauge invariance as a subsidiary condition, a set of invariant amplitudes possessing no kinematical singularities is obtained. It is shown that as a consequence of gauge invariance the fixed-momentum-transfer dispersion relations of Chew, Goldberger, Low, and Nambu[1] (CGLN) probably are valid without subtractions for the (−) amplitudes while a three-pion resonance would perhaps require a subtraction in the (+) amplitudes. The two-pion resonance will certainly require a subtraction for the (0) amplitudes, but to a good approximation the contribution of the two-pion intermediate state is found to produce a simple additive correction to the CGLN (0) formula. The strength of this new term is determined by a parameter which has been introduced by H. S. Wong in treating the photon, three-pion problem.[2] Otherwise, the form of the new term can be expressed in terms of nucleon electromagnetic form factors.

[1] G. F. Chew, M. L. Goldberger, F. E. Low, and Y. Nambu, Phys. Rev. **106**, 1345 (1957).
[2] H. S. Wong, Phys. Rev. Letters **5**, 70 (1960).

ZA7. Three-Body Nuclear Force from Meson Theory. WILLIAM M. FRANK, *U. S. Naval Ordnance Laboratory.*—A Chew-Low approach is applied to the study of the system of three fixed nucleons interacting through gradient coupling with symmetric pseudoscalar mesons. A complete set of symmetries is not easily obtainable. For the purposes of this analysis, the classification of states according to the asymptotic quantum numbers of infinitely separated nucleons is adequate. Two different equations for determining the static nuclear potentials are constructed easily. For the case of one nucleon infinitely separated from the other two, the matrix elements appearing in the potential equations can be evaluated in terms of known matrix elements for the two-nucleon problem. By means of a differential relation, the effects of finite separation can be specified. In this way, the three-nucleon potential is evaluated up to effects of exchange of two mesons between any pair of nucleons. The one-meson exchange part is found to be a sum of the one-meson exchange potential between pairs. The two-meson exchange part shows three-body effects. The corresponding n nucleon meson system can be treated identically.

ZA8. Unified Approach to Strong Interactions at Low Momentum Transfers but Arbitrary Energies.* S. C. FRAUTSCHI, *University of California, Berkeley.*—The "strips" in which the Mandelstam double spectral functions satisfy elastic unitarity conditions are believed to dominate the scattering of strongly interacting particles at low momentum transfers but arbitrary energies.[1] Some consequences, such as a connection between constant total cross sections at high energies and large P waves at low energies, and the possibility of "backward diffraction peaks," will be discussed.

* Supported in part by the National Science Foundation.
[1] G. F. Chew and S. C. Frautschi (to be published).

ZA9. Effect of a $\pi\pi$ Resonance on the Magnetic Moment of Charged Σ Hyperons.* ROBERT B. MARR, *Brookhaven National Laboratory,* LEON F. LANDOVITZ, *Yeshiva University,* AND RICHARD BLANKENBECLER, *Princeton University.*—In order to fit the rather large spatial structure of the nucleon within

the two-pion approximation of dispersion theory, Frazer and Fulco have proposed the existence of a sharp low energy $\pi\pi$ scattering resonance in the $T=J=1$ state. It is of interest to study the effect of such a resonance on the electromagnetic structure of other particles. As a case in point, we have considered the isotopic vector part of the Σ particle anomalous magnetic moment. The approximation used amounts in essence to correcting the perturbation theory calculation of the vertex function for scattering in the intermediate two-pion state. An interesting feature of the Σ-particle form factor is the anomalous threshold present in the two-pion contribution. The correct treatment of rescattering corrections therefore requires more subtle considerations than would otherwise be the case. A preliminary comparison of the results with those of perturbation theory indicates substantial net enhancement of the anomalous moment with odd Σ-Λ relative parity and a net reduction with even relative parity.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

ZA10. Pion Nucleon Scattering Lengths. JACK L. URETSKY, *Purdue University.*—The s-wave pion-nucleon scattering lengths are calculated from equations deduced from the Mandelstam representation. The equations contain only the s-wave projections of the one-nucleon contributions and the unitarity integrals. The $T=\frac{1}{2}$ equation is solved by two different methods, and it is demonstrated that the result cannot be made to agree with experiment. A solution is obtained for the $T=\frac{3}{2}$ scattering length, on the other hand, that is of the correct sign and order of magnitude. It seems clear from this work that the similarity of the two scattering lengths as predicted by Born approximation is very misleading.

ZA11. Theory of the Higher Resonance in Pion-Nucleon Scattering. P. CARRUTHERS, *Cornell University.*—We have calculated the cross section for the reaction $\pi+N\rightarrow 2\pi+N$. The Low equation for the production amplitude is transformed into an integral equation by isolating the true one-meson intermediate states and discarding higher-order contributions. The only part kept in the inhomogeneous term corresponds to the collision of a pion in the nucleon cloud with the incident pion in the resonant $T=J=1$ state, which is simulated by an unstable vector boson. One of the pions scatters off the nucleon in the 3−3 state. Crossed terms are neglected, and the $2\pi-N$ state is described by the static model. The rescattering term is dominant in the resonance region. Quantitative calculations for the $D_{\frac{3}{2}}$ channel leading to a p-wave ($J=\frac{3}{2}$) and an s-wave pion produce a maximum at about 650 Mev. For a $\pi-\pi$ resonance energy squared $s=10$, agreement with experiment is obtained with a width half that suggested by nucleon electromagnetic structure. With our approximations the well-known $T=\frac{1}{2}$, $D_{\frac{3}{2}}$ resonance occurs at the same energy as the $T=\frac{3}{2}$, $D_{\frac{3}{2}}$ resonance.[1] It appears that the third resonance occurs primarily in the $F_{5/2}$, $P_{\frac{1}{2}}$, and $P_{\frac{3}{2}}$ states.

[1] P. Carruthers, Phys. Rev. Letters **4**, 303 (1960).

ZA12. Analytic Continuation of Scattering Amplitudes by Series Expansions. WILLIAM R. FRAZER, *University of California, La Jolla.*—In many applications of dispersion relations one continues a scattering amplitude analytically to unphysical values of $\cos\theta$. This continuation usually has been done by means of the ordinary partial-wave expansion in Legendre polynomials. A new expansion has been found which, in contrast to the Legendre expansion, takes full advantage of the region of analyticity in $\cos\theta$ implied by the Mandelstam representation. This expansion is derived by means of a conformal mapping $w=1(\cos\theta)$ in which the entire cut $\cos\theta$ plane is mapped into the interior of the unit circle in the w plane with the cuts along the circle. A power series in w will converge at all points interior to the cut $\cos\theta$ plane. Within the region in which both the Legendre expansion and the w expansion converge, the latter should converge more rapidly. It should be easier, therefore, to extrapolate to poles to measure coupling constants if the variable w is used instead of $\cos\theta$. The w expansion also should be useful in formulating a dynamical theory of strong interactions, since the divergence difficulties encountered by Chew and Mandelstam may be avoided.[1]

[1] G. F. Chew and S. Mandelstam, Lawrence Radiation Laboratory Rept. UCRL-9126 (March 24, 1960).

ZA13. A New Method of Solution for the Pion-Pion Problem. DAVID Y. WONG, *University of California, La Jolla.*—In the Chew-Mandelstam treatment of the partial wave pion-pion dispersion relations,[1] the branch point at the inelastic threshold was neglected. The left-hand cut was cut off at some point and the distant left-hand cut was replaced by a pole. If a P-wave resonance does exist, their treatment can be improved by considering a box-diagram approximation for the inelastic cut and the distant left-hand cut. The box diagram corresponds to a two-pion intermediate state in the momentum-transfer (energy) variable and a four-pion intermediate state in the energy (momentum-transfer) variable where the four pions are replaced by two-vector particles each representing a pion pair. By the symmetry of the pion-pion problem, the box diagram also will give rise to an approximate imaginary part on the elastic cut and the nearby left-hand cut. However, one can treat these cuts more reliably by the method of Chew and Mandelstam. Thus a procedure can be set up to normalize the coupling strength of the box diagram and calculate the partial wave amplitudes iteratively, starting from the subtraction constants.

[1] G. F. Chew and S. Mandelstam, "Theory of the low-energy pion-pion interaction, Part II," UCRL-9126 (1960).

SUPPLEMENTARY PROGRAMME

SP1. Collective Modes of the Nucleon Charge Distribution.*† THOMAS ERBER, *Illinois Institute of Technology.*—An extended charge distribution and its associated electromagnetic field may possess certain collective modes which are "strongly coupled" in the sense that they are nonanalytic in the coupling constant e^2. Qualitatively the excitation energy E_{exc} of these collective modes is given by $E_{\text{exc}}\sim\eta(\hbar c)/r$, where η depends on the details of the charge structure and r is an effective charge radius. These modes account semiquantitatively for several features of the nuclear giant resonance. It is inviting to apply these ideas to a *single* nucleon: In principle, on the basis of Hofstadter's determination of the nucleon static moments, one can set up an electromagnetic "isobar" theory. In first approximation we take $\eta\sim 1$ and $r\sim 0.8f$; the total energy of the excited mode is then $\sim$1185 Mev which has a suggestive resemblance to the Σ mass. One can go even further and apply these ideas to the electron: Although there is as yet no direct experimental information on a possible electron form factor, the theory of radiation reaction provides a fairly model independent scale factor, i.e., $r=(2/3)e^2/(mc^2)$. This gives rise to an electron "isobar" of energy

$$\sim mc^2[1+3/(2\alpha)]=105 \text{ Mev}$$

which compares favorably with the muon mass. These ideas are a logical extension of the proposals of Bohm and Weinstein.[1]

* Supported by the National Science Foundation.
† To be given at the end of Session Z if the Chairman rules that time permits.
[1] D. Bohm and M. Weinstein, Phys. Rev. **74**, 1789 (1948).

SP2. Gamma-Gamma Directional Correlations in Nd^{147}.*† ATAM P. ARYA, *Pennsylvania State University.*—Directional correlation measurements have been made on the 320—92-kev and 280—320-kev gamma-ray cascades in Pm^{147} following the decay of 11.1-day Nd^{147} with a coincidence scintillation spectrometer using NaI detectors. The observed correlation functions are

$$W(\Theta)=1-(0.1030\pm0.0298)P_2(\cos\Theta)+(0.0107\pm0.0099)P_4(\cos\Theta)$$

and

$$W(\Theta)=1+(0.0710\pm0.0162)P_2(\cos\Theta)-(0.0126\pm0.0103)P_4(\cos\Theta),$$

respectively, for the two cascades. The energy levels of Pm^{147} at ground state, 92-kev, 410-kev, and 690-kev, were found to be $7^+/2$, $7^+/2$, $7^+/2$, and $5^+/2$, respectively. It was found that the 92-kev gamma-ray has a mixture of $(95\pm2)\%$ $M1$ and $(5\pm2)\%$ $E2$ with $\delta_{92}=+(0.229\pm0.143)$, the 320-kev gamma-ray has a mixture of 1% $M1$ and 99% $E2$ with $\delta_{320}=+9.95\pm0.11$, and the 280-kev gamma ray has a mixture of 99% $M1$ and 1% $E2$ with $\delta_{280}=-0.11\pm0.11$.

* This work was supported in part by the U. S. Atomic Energy Commission.
† To be given at the end of Session XA if the Chairman rules that time permits.

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Lindeberg, G. K.—J4
Lindenbaum, Samuel D.—YA2
Lipworth, E.—Y9
Lister, D.—I11
Lobkowicz, Frederick—U2
Lomon, E.—KA10, S5
Longini, R. L.—IA11
Losacco, Frank J.—YA1
Loscoe, C.—IA10
Ludemann, C. A.—I2
Lukasik, Stephen J.—NA1, NA10
Lundgren, T. S.—GA4
Lurio, Allen—Y3, Y10
Lynch, G. R.—N12
Lynn, J. E.—X9

MacDonald, W. M.—R14
MacFarlane, M. H.—Z1
Madigan, John R.—J11
Madsen, V. A.—VA5
Maeda, K.—R8
Magiros, Demetrios G.—OA12
Maglic, B. C.—N12
Mahr, Herbert—H5
Maiman, T. H.—W3
Malhiot, R. J.—KA8, KA9
Mang, H. J.—KA2
Mani, G. S.—MA14
Manley, J. H.—A5
Mann, Lloyd—O2
Mano, Koichi—OA10
Maradudin, A. A.—H2
Marcus, J. A.—IA8
Margoninski, Y.—IA2
Marion, Jerry B.—MA4
Mark, Hans—KA9, XA10
Markowitz, Samuel S.—I12
Marple, D. T. F.—FA2, FA11
Marr, Robert B.—T8, ZA9
Martin, H. J.—N8
Maschke, A.—T5
Maximon, L. C.—S11
Mayer, S. W.—JA11
McCoyd, Gerard C.—DA7
McCrary, J. H.—TA8
McGuire, T. R.—RA2
McKelvey, J. P.—IA11
McMillan, M.—KA10
Mead, James B.—Q14
Meijer, Paul H. E.—RA13, RA14
Meiklejohn, W. H.—RA6
Melkonian, E.—A6, EA4
Meltzer, C.—U4
Mendelson, Sol—H7
Merriam, M. F.—J7
Merrifield, R. E.—C8
Meservey, R.—UA2
Mette, H.—IA10
Meyer, Victor E.—JA7
Michel, M. C.—XA11
Milder, N. L.—G7
Milford, S. N.—DA7, DA8
Miller, A.—RA5
Miller, P. D.—TA1, TA2
Miller, R.—FA10
Miller, W. C.—QA1
Milton, J. C. D.—EA3
Mittleman, Marvin H.—DA9
Mobley, R. C.—B7, P3, P5
Moe, M. K.—Q3
Mohling, Franz—E7
Moldauer, P. A.—VA6
Monari, L.—U4
Moore, J. A.—A6
Moore, W. E.—X10, X11
Morgan, I. L.—TA8
Morse, R. W.—SA3
Mössbauer, R. L.—L1
Motz, H. T.—TA10
Moxon, M. C.—X9
Muether, H. R.—X13
Muldawer, L.—YA9
Mullin, C. J.—QA2
Murray, J. J.—F4

Nagamatsu, H. T.—GA1
Nathans, R.—RA5
Naugle, John E.—R13
Naumann, R. A.—XA11, XA12
Neher, H. V.—R6
Nelson, D. F.—W4
Nelson, J. R.—C7
Nemish, J. W.—NA1
Newby, Neal D., Jr.—Z8
Newson, H. W.—X1, X2
Nicol, James—UA11
Nier, Alfred O.—R3
Nikolic, N. M.—I9
Nissim-Sabat, C.—I10
Northrop, John A.—R9
Novick, R.—Y5

Obenshain, F. E.—A10
Odegaarden, R. H.—A8
Offenbacher, E.—H4
O'Kelley, G. D.—MA1
Olsen, Haakon—S11
Olsen, W. C.—X5
Olson, D. N.—U7
Overseth, Oliver E., Jr.—N7

Pai, S. I.—NA5
Palevsky, H.—X3, X13
Parker, Paul M.—JA7
Parzen, G.—B4
Patel, V. L.—R8
Patty, Richard R.—JA2
Paul, David I.—RA11
Pearlstein, L. D.—Z4
Pearson, J. M.—KA6
Peaslee, David C.—A1, A2
Pell, E. M.—YA7
Percus, J. K.—E5, E6, E9
Perlow, G. J.—TA11, TA12
Pernick, Benjamin J.—NA10
Peshkin, Murray—Z2
Peterson, Robert W.—QA3
Petry, R. F.—XA6
Pevsner, A.—U4
Phelps, A. V.—M1
Phillips, G. C.—I1
Pickart, S. J.—RA5
Pinkerton, J.—G1
Piper, W. W.—FA2
Poindexter, Edward H.—G2
Pomerantz, M. A.—J6
Pond, T. A.—QA5
Poppe, C. H.—TA6
Poskanzer, A. M.—N1
Power, J. L.—XA11
Prakash, Y.—N11
Pratt, G. W., Jr.—RA7
Pratt, W. W.—QA8
Prem, R. J.—N11
Prener, J. S.—YA7
Price, J. F.—NA2
Price, P. Buford—YA8
Price, R. E.—Q13
Prud'homme, J. T.—TA8
Puff, R. D.—RA7
Puppi, G.—U4

Quinn, John J.—C1

Ramaswamy, M. K.—MA10, VA7
Ramler, W. J.—TA12
Ramsey, Norman F.—G1, W7
Randolph, P. D.—X12
Rao, D. A. A. S. N.—MA14
Rayne, J. A.—YA6
Raz, James—BA2
Razavy, M.—KA11
Reed, W. A.—IA8
Reif, Frederick—UA1
Reiner, A. S.—S13
Reiss, Howard—IA15, JA6, JA11, JA12
Reynolds, J. B.—QA5
Reynolds, J. M.—C3, C4
Reynolds, John C.—Z7
Rhee, Y.—U4
Richards, P. L.—UA8
Rikmenspoel, R.—Q9
Riney, T. D.—YA11
Roberts, L. D.—Y11
Robinson, E. L.—MA13
Robinson, H. G.—G6
Rogers, W. L.—TA7
Roederer, Juan—V1
Rose, D. C.—R7
Rose, P. H.—B5, B6, P1
Rosen, Jerome—B3
Rosenthal, Jenny E.—W6
Ross, Marc H.—N9
Roth, H.—IA7
Rothstein, Jerome—OA1
Roush, M. L.—I2
Rubin, Allen G.—GA3
Rubinow, S. I.—OA7
Rupprecht, G.—D3, D4
Ryan, F. M.—FA10

Sachs, Mendel—T12, T13
Safford, G. J.—A6
Sah, Linda Chang—I12
Salzman, Freda—S8

Salzman, George—S8
Sandweiss, J.—N2, N5
Sanford, J.—N2, N5
Sastry, K. S. R.—XA6
Satchler, G. R.—MA11, S7, VA3, VA11
Sayres, A.—I11
Scanlon, Joseph H.—DA8
Schawlow, A. L.—W2, W4
Scheer, Milton D.—H3
Scherr, Charles W.—DA6
Schieve, W. C.—J6
Schiller, Ralph—OA8
Schiminovich, S.—T4
Schindler, A. I.—C5
Schkolnick, Leon J.—YA1
Schlein, P.—U4
Schmid, E. W.—Z5
Schmidlin, F. W.—UA7
Schlosser, H.—IA6
Schneps, Jack—N10
Schopper, H. F.—U7
Schröder, I.—A6
Schwartz, M.—T1
Schwartz, R. B.—X6
Schwarzschild, A.—QA11
Schwebel, Solomon L.—T12, T13
Sclar, N.—IA9
Scott, E. J.—IA5
Sears, F. W.—LA2
Sedney, R.—NA3
Seeman, N.—N3
Segall, B.—C2, FA11
Seman, M.—J1
Seth, Kamal K.—VA4, X1
Shapiro, Sidney—UA11
Sharp, R. D.—Q1
Shaw, Gordon L.—N9
Shea, M. F.—QA1
Sherr, R.—I5
Sheer, R. E., Jr.—GA1
Sherr, R.—Q8
Shimony, Abner—E3
Shively, F. T.—N8
Shrader, E. F.—Q2, TA7
Shull, F. B.—I3
Shulman, R. G.—WA4
Signell, Peter—U1
Signer, Peter—R3
Sikorski, M. E.—YA3
Silverman, B. D.—D5
Silverman, Jeremiah N.—DA6
Simmons, Charles A.—FA7
Singh, P. P.—P4, X5
Skeel, W. L.—MA10
Skinner, G. T.—NA4
Slaughter, G. G.—X8
Slifkin, Lawrence—H9, R10
Slobodskoy, Alexis—IA13
Smith, D. R.—QA6
Smith, K. F.—Y9
Smith, Paul H.—UA11
Smith, R. J.—C5
Smith, Ronald K.—QA3
Smith, W. G.—QA10
Smoluchowski, R.—J7, J9
Soldano, B. A.—ZA1
Sommerfield, Charles M.—T6
Scuth, J. C.—NA3
Spaulding, S. W.—H4
Speiser, D.—T4
Sperber, Daniel—Z3
Speth, A. I.—NA5
Stabler, Robert C.—A3
Stairs, Douglas—U3
Stearns, R. L.—X13
Steffen, R. M.—KA5, QA13
Stehney, A. F.—TA11, TA12
Steinberg, P. H.—N11
Stern, Edward A.—C6
Sternglass, E. J.—ZA5
Stevenson, M. L.—N12
Stiller, B.—N3
Stoering, J. P.—I7, TA3
Stonehill, D.—N2, N5
Strakhov, N. A.—YA3
Strand, R.—U4
Strong, K. A.—X12
Sugawara, Masao—KA4
Suh, K. S.—DA5
Summers, C. L.—Y4
Swan, J. B.—QA12
Swift, C. D.—XA9, XA10

Tabony, Robert H.—X2
Taft, Horace—F2, N2, N5
Taketani, H.—MA12
Tanaka, Katsumi—KA4
Tanaka, Tomoyasu—RA13, RA14
Tang, Y. C.—Z4, Z6
Tassie, L. J.—S13
Teitler, S.—FA12
Terrell, James—EA2
Teutsch, W. B.—IA7, J3
Thaddeus, P.—Y5
Thieberger, R.—S1
Thomas, D. G.—WA3
Thomas, W.—QA4
Thomson, J. O.—Y11
Thorndike, A. M.—F1
Thwaites, T. T.—QA8
Tilley, D. R.—I6
Tobocman, W.—VA2, VA8, VA10
Toll, J. S.—T3, T10, T11
Tolnas, Edwin L.—Y10
Tomboulian, D. H.—JA4
Tombrello, T. A.—MA14
Trees, R. E.—DA1
Trehan, P. N.—Q9
Trulio, John G.—E1
Turcotte, Donald L.—NA7
Turkot, F.—N6

Unterleitner, Fred C.—D2
Uretsky, Jack L.—ZA10

Valenta, M. W.—D1
Van Patter, D. M.—Q4, Q9
Vaughn, F. J.—I8
Vook, Richard W.—H12
Vosko, S. H.—J9

Waite, T. R.—OA13
Walker, J. C.—Y7
Wallis, R. F.—J13
Walsh, Peter—DA2
Walter, R. L.—TA6
Warburton, E. K.—I8, Q1
Watson, Kenneth M.—DA9
Weakliem, H.—W1
Weatherford, W. D., Jr.—NA8
Weber, J.—ZA2
Wegener, H. H. F.—A10
Weidner, R. T.—G5
Weinberg R.—I10
Weiss, G. H.—H2
Weisskopf, V. F.—LA1
Welton, T. A.—J2
Wentworth, R. C.—R14
Wertheim, G. K.—A9
Westgard, J.—U4
Wheeler, J. A.—K1
White, M. B.—Y9
Wiegand, D. A.—J7
Wildermuth, K.—Z4, Z5, Z6
Wilkinson, R. G.—XA6
Williams, C. E.—JA1
Williams, Dudley—JA2
Williams, F. E.—YA7
Williams, Wendell S.—H11
Williamson, R. M.—I6
Willis, C. R.—E8
Wilson, R. R.—L2, U7
Wilson, Richard—U3
Winter, Rolf G.—OA11
Wise, P. R.—JA5
Wittekindt, R. H.—NA11
Wittkower, A. B.—B5, P1
Wojtowicz, Peter J.—RA12
Wolfenstein, Lincoln—KA3
Wolke, R. L.—MA1
Wolsky, S. P.—JA10
Wong, Calvin—TA3
Wong, David Y.—ZA13
Wood, R.—I5
Woodward, W. M.—N6
Wooten, Frederick O.—FA4
Wright, George B.—FA5
Wright, K. A.—MA7
Wu, C. S.—QA4
Wyckoff, J. M.—P6

Xuong, Nguyen H.—N12

Yang, G.—G8
Yaramis, B.—MA5
Yevick, George J.—E5
Yntema, J. L.—MA9, TA12

Zacharias, J. R.—LA3
Zaidi, M. H.—DA5
Zawislak, F. C.—MA6
Zdanuk, E. J.—JA10
Zebouni, N. H.—C3
Zeidman, B.—MA9
Zemel, J. N.—IA3, IA5
Zenger, J. H.—XA9, XA10
Zerby, Clayton D.—S6
Ziegler, B.—P6
Zimmerman, R. L.—Q3
Zorn, Jens C.—U5

Hotel Information

The New Yorker is the headquarters hotel. Reservations should be sent directly to Mr. Thomas Hurd, Front Office Manager of the New Yorker, in the manner directed below. Please tear off the attached and use as your room reservation blank. Be sure to specify the persons for whom reservations are being made. All rates quoted are for the room, and in the event of more than one person occupying the room the rate can be shared. If a third person is housed in the room, the cost of the extra "roll-away" bed will be added to the cost of the room.

If a room at the rate requested is not available, one at the nearest available rate will be reserved for you. Be sure to bring the confirmation slip with you as proof of your reservation. In fairness to others, please make a cancellation if your plans change. Unless otherwise requested, the hotel will hold reservations only to 6 P.M. of the day of your arrival. Check-out time is 3 P.M.

Hotel Rates

Hotel	Room and Bath for one per day	Double-Bed Room with Bath for two per day	Twin-Bed Room with Bath for two per day	Suites Living Room Bedroom and Bath for one or two per day
New Yorker 34th Street at 8th Avenue	$8–$14.50	$11.50–$18.00	$15.50–$20.00	$35.00 and up

NOTE: All rates subject to New York City 5% hotel room tax.

Tear Off Tear Off

To: Front Office Manager
Hotel New Yorker
34th Street and 8th Avenue
New York, New York

A.P.S.

Please enter my reservation for a single / double / twin bedroom at approx. $..... to $..... per day for the 1961 A.P.S. Meeting. I / We plan to arrive..... and remain until .....

Print below persons in your party.

.....
Signature

.....
Address (Street or P.O.)

.....
Town or City and State

Preliminary Announcement of the 1961 March Meeting at Monterey

The 1961 March meeting will be held at the U. S. Naval Postgraduate School in Monterey, California, from Monday through Thursday, March 20–23. The Divisions of High-Polymer Physics, Solid-State Physics, and Chemical Physics will feature sessions during this meeting. The sessions of the first-named Division begin on the 21st and extend to the 23rd. Accommodations will be available at the Mark Thomas Inn and the Casa Munras Hotel. Motel rooms will also be available in the area. Make your reservations as soon as possible, if not already made, and make them by writing to the Monterey Peninsula Convention Bureau, P. O. Box 1571, Monterey, California. Be sure to say that you are attending the meeting of The American Physical Society.

Deadline for the meeting was January 13, and there was a special deadline January 6 for papers of the Division of High-Polymer Physics. In the highly unlikely event that this Bulletin appears before these dates are past, you may look into the previous issue of this Bulletin to find out how to address your abstracts.

Preliminary Announcement of the 1961 Spring Meeting

The 1961 Spring meeting will be held in Washington, D. C., on Monday, Tuesday, Wednesday, and Thursday, April 24–27. The headquarters hotel is the Sheraton-Park. The sooner you write to it for your room, the better. This advice is given early and emphatically, because last year there were more of our members who asked for rooms than there were rooms set aside for them (an event unprecedented in our history, by the way) and the Local Committee was hard put to it to get a supplementary quota. If this situation is destined to arise again this year, the sooner it arises the better will be the chance of remedying it. Therefore write as soon as possible for your room and do not fail to mention that you are coming to the meeting of The American Physical Society. Deadline will be February 10.

1961 International Conference on Photoconductivity

The "1961 International Conference on Photoconductivity" will be held at Cornell University, Ithaca, New York, on August 21–24. This is accepted as a "topical conference" by The American Physical Society, and other sponsors are the International Union of Pure and Applied Physics and the Office of Naval Research. The emphasis of this conference will be on the fundamental aspects of photoconductivity and phenomena directly related thereto. The conference will conform to the pattern of the 1954 conference on photoconductivity held at Atlantic City. Parallel sessions will not be allowed, and so the programme must include not more than about twenty half-hour papers and forty 15-minute papers, probably only a small percentage of those that may be contributed. Papers on specific devices and applications will be excluded. All members of the Society are allowed to attend this Conference, but those who wish to go must signify their wish **not later than July 1** to the Conference Secretary, Dr. A. R. Hutson, Bell Telephone Laboratories, Murray Hill, New Jersey. To him must go also the abstracts of contributed papers, and these must conform to the same rules as are imposed on those submitted to general meetings of the Society. **Deadline for abstracts is March 31, 1961.**

1961 Gaseous Electronic Conference

The 1961 Gaseous Electronics Conference, fourteenth of the series, will be held at the General Electric Research Laboratories ("the Knolls") at Schenectady, New York, on October 11–13. Former conferences were sponsored by our Division of Electron Physics, which still contributes a member to the Organizing Committee. This Conference has been accepted as a Topical Conference of The American Physical Society. Like its predecessors it is to deal with the basic collision processes occurring in ionized gases, with the mechanisms of electrical breakdown and those of operation of electrical discharges, and with plasma physics in general, but papers on specific devices are excluded. All members of the Society have the right to attend this Conference and to submit contributed papers, but the Organizing Committee may accept or reject these as it chooses.

Abstracts of contributed papers are to be sent to C. J. Gallagher, General Electric Research Laboratories, Schenectady, New York, and must reach him not later than August 25, 1961. Abstracts must conform to the same regulations as are imposed on those submitted for general meetings of the Society. The Organizing Committee will not accept a greater number of contributed papers than is compatible with its intent to keep the meeting within three days, to avoid simultaneous sessions, and to provide adequate time for presentation and discussion of the papers that are accepted.

Prizes Awarded by The American Physical Society

The 1960 American Physical Society Prize Sponsored by Hughes Aircraft Company

The American Physical Society Prize sponsored by Hughes Aircraft Company has been awarded by our Council to GEORGE FEHER, the ceremony of award having been held on November 25, 1960, at the banquet of our Chicago meeting. Funds for this prize were given, as the name implies, by Hughes Aircraft Company. The citation is as follows: "The prize is awarded to George Feher for originating and developing the electron-nuclear double-resonance technique, and for applying it in solid-state and nuclear research."

The 1961 Oliver E. Buckley Solid-State Physics Prize

The 1961 Oliver E. Buckley Solid-State Physics Prize has been awarded by our Council to WALTER KOHN, and it is expected that the ceremony of award will be held on February 3, 1961, at the banquet of our New York meeting. Funds for this prize were given by Bell Telephone Laboratories. The citation is as follows: "The prize is awarded to Walter Kohn for his extension and elucidation of the foundations of the electron theory of solids."

The 1961 Dannie Heineman Prize

It is probable that a Dannie Heineman Prize will be awarded in 1961. Funds for this prize have been given by the Heineman Foundation and are administered by the American Institute of Physics, which has delegated the choice of a prizewinner to a Committee appointed by The American Physical Society acting through its Council. Members of the Society are privileged to suggest candidates for this prize by writing to the Chairman of the Committee, who is Professor Frederick Seitz, University of Illinois, Urbana, Illinois. The terms of the donation specify that the prize is to be awarded "for outstanding articles in the field of mathematical physics published in scientific journals." Previous winners of Dannie Heineman prizes are Murray Gell-Mann and Aage Bohr.

Proceedings of the American Physical Society

Minutes of the Fall Meeting of the New England Section at the University of New Hampshire, Durham, New Hampshire, on October 22, 1960

THE New England Section of the American Physical Society (NESAPS) held its annual fall meeting on Saturday, October 22, at the University of New Hampshire, Durham, New Hampshire. This was a joint meeting with the New England Section of the American Association of Physics Teachers (NESAAPT); the success of the program would indicate mutual benefits to be gained from future combined meetings of this nature. A total registration of 111 was recorded for the two sections. Professor Harry Hall, Chairman of the Department of Physics at the University of New Hampshire, handled the arrangements with the aid of other members of the Department. Members of the Section viewed the research facilities of the Department and enjoyed the beautiful locale of the University.

The morning session of the NESAPS consisted of two substantial contributed papers which were presented and discussed at length. Members of the Section then joined the morning session of the NESAAPT to hear the paper,

High Vacuum Experiments for the Elementary Laboratory with Simple Equipment. John G. King, *Massachusetts Institute of Technology.*

In the afternoon, after a short business meeting of the NESAPS, the members of both societies enjoyed an afternoon session of three excellent invited papers. The invited papers were:

Recent Developments in the Field of High-Energy Accelerators. M. Stanley Livingston, *Massachusetts Institute of Technology.*

Measurement of the Weight of the Photon. Robert V. Pound, *Harvard University.*

Intensity-Time Variations in the Cosmic Radiation. John A. Lockwood, *University of New Hampshire.*

At the business meeting of the NESAPS, the following officers were elected by the Section:

Chairman—H. H. Hall, University of New Hampshire

Vice-Chairman—E. P. Clancy, Mount Holyoke College

Secretary-Treasurer—P. J. Bray, Brown University

Executive Committee—

D. A. Park, Williams College

G. J. Holton, Harvard University

Philip J. Bray, *Secretary-Treasurer*
New England Section

Contributed Papers

1. Influence of Wet and Dry Ambients on Fast Germanium Surface States,* Y. Margoninski,† *Brown University.*—Simultaneous measurements of surface recombination velocity and added trapped charge density in the fast states as a function of surface potential were carried out on the same *n*-type specimen which was subjected to the following gaseous ambient cycles: (a) room air vacuum; (b) dry air vacuum; (c) dry oxygen vacuum; (d) dry nitrogen vacuum; (e) wet nitrogen vacuum; (f) wet oxygen vacuum. The most important results of these measurements were: (1) dry nitrogen had no influence whatsoever on any of the surface state parameters; (2) dry oxygen affected only the density of states and the unperturbed surface potential; (3) wet nitrogen and wet oxygen had almost the same and most pronounced effect on the fast surface states. Baking for over 3 hr at 90°C in vacuum decreased the energy and density of states but did not change the capture cross section.

* This work was supported by a contract with the U. S. Air Force Cambridge Research Center, Air Research and Development Command.

† On leave from the Department of Physics, Hebrew University, Jerusalem. Present address: Research Laboratory, Raytheon Company.

2. Spectrum of Energy Lost to Phonons in the Mössbauer Effect. David Park, *Williams College.*—A calculation of the effects of phonon exchange on a simple gamma-ray level of an atom in a homogeneous crystal will be presented. First a formula is derived for the probability of the emission or absorption of a specified number of phonons of any energy as a function of the temperature. This formula is then used to derive the probability that the atom exchanges a given amount of energy with the crystal in a gamma transition. The resulting spectrum has a delta-function peak corresponding to zero energy loss (this is the Mössbauer effect) and a lower peak in the neighborhood of $h\theta$. This second peak is not high enough to interfere with experiments carried out under ordinary conditions of resolution.

Minutes of the Fall Meeting of the Ohio Section Held at The Ohio State University, Columbus, Ohio, October 28 and 29–1960

THE regular Fall Meeting of the Ohio Section of the American Physical Society was held at The Ohio State University in Columbus, Ohio, on Friday afternoon, October 28, and Saturday morning, October 29, 1960. With chairman Albert B. Stewart of Antioch College presiding, the Friday afternoon program began with 4 invited papers in the area of low-temperature physics:

1. **Low-Temperature Physics.** John G. Daunt, *The Ohio State University.*
2. **Low-Temperature Stable Oscillators.** Clifford V. Heer, *The Ohio State University.*
3. **Low-Temperature Specific Heats in Magnetic Systems.** Richard A. Erickson, *The Ohio State University.*
4. **Experimental Work on Helium Three.** D. O. Edwards, *The Ohio State University.*

Then followed a fifteen-minute intermission during which cider, cookies, and coffee were served by the Physics Department of The Ohio State University. The remainder of the afternoon program consisted of contributed papers numbered 5 to 11, the abstracts of which appear below. Visits were arranged to Dr. Daunt's low-temperature laboratory to fill the time before the dinner hour.

On Saturday morning after greetings and welcome by Professor H. H. Nielsen, Dr. John F. Eichelberger of Mound Laboratory, the Vice-Chairman, presided. Two invited papers in radio astronomy were presented:

12. **New Advances in Radio Astronomy.** John D. Kraus, *The Ohio State University.*
13. **The Radio Sky.** H. C. Ko, *The Ohio State University.*

A fifteen-minute social period was again enjoyed with refreshments provided by the Physics Department of Ohio State University. Seven additional contributed papers followed, numbered 14 to 19. After lunch, trips to The Ohio State Radio Astronomy Laboratories were arranged, and the new ideas on undergraduate laboratories were shown.

The attendance was very good, at least 150 in each session. A resolution was proposed and passed expressing the appreciation of the Ohio Section to The Ohio State University and to the committee in particular who did so much to make this a notable meeting.

Leon E. Smith, *Secretary*
Ohio Section

Contributed Papers

5. Low-Temperature Research on Polonium-210. J. W. Snider,* E. W. Wiederhold, and R. J. Spry,† *Mound Laboratory.*‡—As part of the program of research on the properties of polonium-210 which has been under way at Mound Laboratory for many years, the possibility of a superconducting transition in this element was investigated. The apparatus was designed to make use of the Meissner effect to indicate such a transition. The sample was prepared by evaporing a thin film of metallic polonium on the inside of a quartz capsule which subsequently was sealed. The sample consisted of 2.46 mg of polonium. No evidence of superconductivity was found from 4.2°K to 1.6°K.

* Permanent address: Physics Department, Miami University.
† Presently at Department of Physics, University of Illinois.
‡ Mound Laboratory, operated for the U. S. Atomic Energy Commission.

6. Low Field de Haas-van Alphen Studies of the Fermi Surface of Magnesium.* W. L. Gordon, A. S. Joseph, and T. G. Eck, *Case Institute of Technology.*—A null deflection torsion method permitting automatic recording of torque as a function of $1/H$ has been employed to study the de Haas-van Alphen oscillations in the magnetic susceptibility of single crystals of magnesium in fields up to 19 kgauss and at temperatures of 4.2°K and below. Analysis of the angular dependence of the de Haas-van Alphen periods on field orientation relative to crystalline axes has yielded extremal cross sections of the Fermi surface which agree closely with portions of the free electron construction proposed by W. A. Harrison.[1]

* Supported in part by the Research Corporation and the U. S. Air Force Office of Scientific Research.
[1] W. A. Harrison, Phys. Rev. 118, 1190 (1960).

7. Derivation of Irreversible Rate Equations for a Particular Source of Relaxation. Robert L. Peterson,* *Case Institute of Technology.*—For systems in which the interactions between particles form the dominant or only part of the Hamiltonian, it often is not clear how the approach to equilibrium of some of the properties of the system can be described mathematically—that is, if it is not evident how to divide the Hamiltonian into unperturbed and perturbation terms, the conventional perturbation description of the approach to equilibrium cannot be utilized. Spin-spin relaxation presents such a problem. If it is hypothesized that the relaxation is due to the deviations (from their mean values) of the interactions between pairs of particles, it is found possible to make a perturbation expansion to determine the approximate time dependence of the density matrix elements. No random phase assumption is used in the derivation, the statistical nature of the interaction deviations playing a largely similar (but not identical) role. If a representation is used in which any external interactions are diagonal, the rate equation for the diagonal density matrix elements becomes, in second order, the master equation with detailed balance, plus a term A which cannot be evaluated within the formalism. Since the master equation with detailed balance describes an approach to equilibrium in which all states are equally probable, which is a nonphysical result in this case, it is suggested that A would describe the correct equilibrium values. The rate equation for the off-diagonal elements is very simple, contains no undetermined term, and apparently is new.

* This work was supported by the U. S. Atomic Energy Commission.

8. Electron Spin Resonance in Some Bivalent Silver and Copper Salts.* B. Y. Cho and L. C. Brown, *The Ohio State University.*—The electron spin resonance spectra of Ag^{++} and Cu^{++} in silver picolinate, copper picolinate, and tetrapyridine copper persulfate have been investigated at room temperature and at liquid nitrogen temperature. The picolinate spectra (from powdered crystals) yield the following values for g: for Ag^{++}, $g_\perp = 2.039 \pm 0.002$, $g_\parallel = 2.180 \pm 0.002$; for Cu^{++}, $g_\perp = 2.053 \pm 0.002$, $g_\parallel = 2.235 \pm 0.002$. The persulfate spectrum is more symmetrical possibly indicating that the variations in g are small in comparison with the line widths ($g = 2.082$

± 0.002). No remarkable differences were noticed in the spectra at liquid nitrogen temperature. The samples were placed at our disposal by John Ragle, Department of Chemistry, University of Massachusetts.

* Supported in part by the U. S. Air Force Office of Scientific Research and by the Kettering Foundation.

9. Nuclear Magnetic Resonance Study of Hindered Rotation in CF_2H-CF_2-CFH Br.* DANIEL D. ELLEMAN AND DUDLEY WILLIAMS, *The Ohio State University*.—At room temperature the F^{19} resonance associated with the CF_2H group in CF_2HCF_2CFH Br consists of two chemically shifted wide doublets instead of the single wide doublet due to a spin-spin interaction with the proton, which might be expected for this group in a molecule in which there is free rotation about C−C bonds. The resonance in question now has been studied over a range of temperatures between −96°C and +100°C. As the temperature increases, there is a marked change in the appearance of the resonance. The observed changes are interpreted in terms of a strongly temperature-dependent relative chemical shift between the F^{19} sites in two different configurations of the molecule associated with hindered internal rotation. At +100°C, the relative chemical shift is so small that a single wide doublet is observed. Each component of the wide doublet consists of more closely spaced components attributed to spin-spin interactions of F^{19} in the CF_2H group with spin $\frac{1}{2}$ nuclei in other parts of the molecule.

* Supported in part by the U. S. Air Force Office of Scientific Research.

10. Nuclear Magnetic Resonance Spectra of Several Fluorinated Unsaturated and Saturated Hydrocarbons.* HENRY M. BEISNER, *The Ohio State University*.—The nuclear magnetic resonance spectra of one fluorinated propyne ($CF_3C{\vdots}CH$),[1] four halogenated propenes and butenes (CCl_2CHCF_3, $CClFCHCF_3$, $CF_3CClCClCF_3$, and $CF_3CClCFCF_3$), and two halogenated cyclopentenes (1,2-dichlorohexafluorocyclopentene and perfluorocyclopentene) have been investigated. In general, chemical shifts could be determined for H^1 and F^{19} at various intramolecular sites; in most cases, spin-spin coupling constants could be determined. The molecular parameters obtained from analyses of the observed spectra are tabulated.

* This work was supported in part by the U. S. Air Force Office of Scientific Research.
[1] The spectrum for this compound was taken by D. D. Elleman.

11. Solid-State Detectors as dE/dx Counters.* K. A. GEORGE AND G. F. DELL, *The Ohio State University*.—Surface barrier solid-state particle detectors have been used to detect low energy charged particles with resolutions less than 1%. However, the range of protons of energy greater than 6 Mev is greater than the active depth of the detectors. Consequently, at these particle energies the detectors become nonlinear and pulse pileup occurs. We have utilized these detectors as dE/dx counters at proton energies of 7 Mev. The detectors are biased such that the range of all particle groups of interest is greater than the active depth of the detector. The pulse heights of the proton groups are then proportional to the energy lost in the active region of the detector. Experimental details will be reported.

* Supported in part by the U. S. Atomic Energy Commission.

14. Effect of Monoenergetic Neutron Pulses on Infrared Detectors. JOHN C. MARSHALL AND WILLIAM L. LEHMANN, *Air Force Institute of Technology*.—Lead telluride and lead sulfide infrared cells were bombarded by 14.1-Mev neutrons in pulses of 100-μsec duration at the rate of 1000 pulses per sec. The neutrons were produced by our 400-kev PN-400 Van de Graaff generator using the $H^3(d,n)He^4$ reaction. The flux of the infrared cell was approximately 6×10^7 (neutrons)/(cm^{2}sec) during the pulse. Crude calculations indicate that the effect of the neutrons should be of the same magnitude as the noise voltage present from other sources. Measurements were taken of noise voltage and time constant before, during, and after neutron radiation. No change was noted. Germanium diodes biased in the reverse direction gave positive results. This indicates that PbS and PbTe cells are insensitive to fluxes of 14.1-Mev neutrons less than 6×10^7/cm^{2}sec.

15. Decay Energy of Ba^{133}.* W. L. SKEEL, M. K. RAMASWAMY, AND P. S. JASTRAM, *The Ohio State University*.—We have redetermined the transition energy for the decay of Ba^{133} to Cs^{133} to be 489 kev, confirming Gupta's results, in disagreement with the estimate of 700 kev from beta-decay systematics. The *ft* values for the orbital capture transitions to the 437- and 381-kev levels, as well as gamma cascade studies reported previously, support a single-particle description for all of the low-lying levels of Cs^{133}, with the possible exception of the one at 158 kev. The doublet splitting between the $d_{3/2}$ and $d_{5/2}$ levels is found to be 300 kev.

* Supported by the U. S. Atomic Energy Commission.

16. Spin of the 2.3-Mev Level in Zinc-68.* M. K. RAMASWAMY, *The Ohio State University* (introduced by P. R. Jastram).—A search for an electric monopole (EO) transition from the 2.3-Mev level to the ground state of Zn^{68} has been made using plastic scintillators and a shielded anticoincidence arrangement. A search was made for 2.3-Mev internal conversion electrons arising from the EO mode of de-excitation, with negative results. An upper limit of $(5\pm25)\times10^{-9}$ conversion electrons per decay of Ga^{68} could be set. If we assume a value of 0.11 for ρ (the EO strength parameter) and the single-particle model to be valid, the expected yield was 84×10^{-9}. The measured upper limit is interpreted as evidence against a possible 0^+ assignment for the 2.3-Mev level and is consistent with an assignment of 2^+ from recent angular correlation work.[1]

* Work done at Johns Hopkins University; supported in part by the U. S. Atomic Energy Commission.
[1] M. K. Ramaswamy and P. S. Jastram, Nuclear Phys. **16**, 113 (1960).

17. Nuclear Structure Effects in Cs^{133}.* M. K. RAMASWAMY, *The Ohio State University* (introduced by P. S. Jastram).—The 79-kev transition in Cs^{133}, which is known to be *l*-forbidden ($\Delta l=2$) magnetic dipole ($M1$), has been analyzed for penetration effects suggested by Church and Weneser. A value of 6.5 ± 2.6 is found for λ, the ratio of the matrix element due to penetration of the atomic electron into the nucleus to the matrix element due to $M1$ gamma emission. This value of λ is to be compared with the range 5–10 obtained by Church and Weneser for *l*-forbidden ($\Delta l=2$) transitions using empirical gamma matrix elements and single-particle wave functions to evaluate the electron matrix element.

* This work was supported by the U. S. Atomic Energy Commission.

18. Search for Two-Photon Decay from the First Excited State in Ca^{40}.* G. F. DELL, P. S. JASTRAM, AND H. J. HAUSMAN, *The Ohio State University*.—We have investigated the reaction $Ca^{40}(p,p'2\gamma)3.35$ Mev in search of the presence of two-photon decay from this excited state. Both the ground state and the 3.35-Mev first excited state of Ca^{40} have spin O and even parity. Since a single photon decay is strictly forbidden, one might expect two-photon decay to compete favorably with the other first-order decay modes such as pair decay and internal conversion. A thick target of calcium metal was bombarded with 7-Mev protons from The Ohio State Cyclotron and gamma rays from the target detected in coincidence by two NaI crystal counters. A conventional fast-slow triple coincidence circuit, having a time resolution of 20 nanosec, was used for the measurement. We could detect no evidence for

two-photon decay from the first excited state in Ca^{40}. A preliminary estimate of an upper limit of 1.4% has been set for the ratio of two-photon decays to all other decay modes from the state.

* Supported in part by the U. S. Atomic Energy Commission.

19. **p-Wave Strength Function.*** T. K. KRUEGER, *Wright-Patterson Air Force Base,* AND B. MARGOLIS, *The Ohio State University.*—Recently[1] it has been suggested that neutron capture cross sections in the region of 10 to 100 kev could be used to determine the p-wave strength function for neutrons. Because of the nuclear spin-orbit force, the possibility arises of having each p-wave giant resonance split into a $p_{\frac{1}{2}}$-$p_{\frac{3}{2}}$ doublet. By using a diffuse well optical model potential with surface peaked absorption and a spin-orbit force of conventional strength,[2] we have calculated the p-wave strength function as a function of atomic weight. We do not find any spin orbit splitting of the p-wave resonance near $A=100$. The question of how the physical parameters must be changed to get a spin-orbit splitting will be discussed. Comparison of the calculated results with experiment will be made.

* Supported in part by the U. S. Air Force and the U. S. Atomic Energy Commission.

[1] K. K. Seth, *Proceedings of the International Conference on the Nuclear Optical Model* (The Florida State University, Tallahassee, 1959).
[2] F. Bjorklund, footnote 1.

MEETINGS AND DEADLINES THROUGH JANUARY 1962

Place	*Meeting dates*	*Deadline date*
Monterey*	March 20–23	January 13
Washington	April 24–27	February 10
Mexico City	June 22–24	April 7
Chicago	November 24–25	September 22
Los Angeles*	December 27–29	undecided
New York	January 24–27, 1962	undecided

Abstracts for the meetings marked with asterisks are to be sent to Professor E. L. Hahn, University of California, Berkeley 4, California, and must reach his office not later than the corresponding deadline date. Abstracts for the other meetings listed above are to be sent to Karl K. Darrow, American Physical Society, Columbia University, New York 27, New York, and must reach his office not later than the corresponding deadline date. Take note that abstracts mailed the day before deadline day often fail to arrive in time: the last postal delivery of the day usually comes to our office before 2 p.m. For meetings handled at this office, *allow at least two days for abstracts sent by airmail from points east of the Mississippi, and longer for those sent from farther west.* Abstracts postmarked (at the point of dispatch) on deadline day are instantly rejected. No abstract postmarked (at the point of dispatch) on deadline day ever reaches the office on time, nor does any abstract postmarked at any point west of the Rockies on the day before deadline day. Some abstracts arrive with covering letters dated three or more days before the postmark; it may be a good idea for you to put your abstract into a United States mail box with your own hands. Finally, if time is scant, fold your abstract and mail it in an envelope of size 9½ by 4¼ inches or thereabouts; for if you mail it in a "manila" envelope large enough to accommodate it without folding, it may very well arrive after the deadline. *The privilege of contributing papers to meetings of The American Physical Society is restricted to the members of the Society and to nonmembers whose papers are sponsored by members.*

DIVISIONAL MEETINGS AND TOPICAL CONFERENCES (see pages 89 and 90)

Monterey	High-Polymer Physics	March 21–23	January 6
Ithaca	Photoconductivity	August 21–24	March 31
Schenectady	Gaseous Electronics	October 11–13	August 25

RULES AND INSTRUCTIONS FOR THE PREPARATION OF ABSTRACTS

The Council has ordered that abstracts shall be not longer than two hundred (200) words or the equivalent thereof. In reckoning equivalence, a footnote is equated to ten words or to its actual length in words, whichever is the greater; each line in a table to ten words; a "display" formula—one that requires a line to itself—is an expensive luxury equated to forty words. By-lines are not counted as part of the 200 words, and therefore addresses are condensed to the minimum in them. If you want to spend a lot of your precious 200 words in describing your exact location and the exact compartment of your organization in which you work, you have that privilege.

Two copies of each abstract must be sent to the appropriate office. They must be typewritten; *one must be an original*, the other may be an original or a carbon copy. *Carbon copies will not be accepted in lieu of originals:* they smear. *Abstracts* (including titles, by-lines, and footnotes) *must be double-spaced:* single-spaced manuscripts are too crowded to permit the editorial markings to be made with ease and clearness. *Each abstract must be confined to a single page:* if it is too long for a single page it is too long to be printed. If we receive an abstract typed on two pages, we print only its first page. *Write each abstract as a single paragraph:* the suppression of paragraphs costs time and labor to the editors. *Do not use very thin paper:* a sheet of very thin paper may cause extraordinary trouble when mixed with sheets of reasonable thickness. *Tables too broad to fit into one column of the Bulletin will be left out.* The American Institute of Physics will bless you if you type first the title of your abstract in lower-case with capitalized initials, then your name in capitals, then the name of your institution in lower-case underlined with capitalized initials. It is a pleasure to report that those who qualify for this blessing are increasing in number but are still quite a bit short of 100% of the total. Issues of the *Bulletin* are always appreciably delayed because the editors have to do what the authors should have done.

Remember the rule of the Council that, if an author submits more than one abstract, all but one must go into the Supplementary Programme. In enforcing this rule, an abstract is credited to the author whose name appears first in the by-line.

It has now become an expensive business to make any change in an abstract, even the smallest, after it has been received. By order of our Council "A change in an abstract will be permitted only at the discretion of the Secretary or his deputy, and only if TEN DOLLARS is enclosed with the letter in which the change is requested." As heretofore, an abstract will not be withdrawn from proof unless the asker sends ten dollars with his request.

New Instructions

(*a*) *If it is wished that two abstracts be scheduled consecutively, write on the first "To be scheduled before abstract ..... by ....." and on the second "To be scheduled after abstract ..... by ....."*

(*b*) *In general, all instructions about an abstract should be typed at the bottom of the page that has the abstract on it, never in a covering letter. Covering letters get separated from abstracts!*

(*c*) *If a member insists that his paper be scheduled for a particular day or not on a particular day, he will get his wish, but usually at the price of having his contribution included in a session to which it is irrelevant.*

The American Physical Society

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